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PROYECTO FIN DE CARRERA

A NON-INTRUSIVE APPLIANCE LOAD MONITORING SYSTEM FOR IDENTIFYING KITCHEN ACTIVITIES

Ingeniería de Telecomunicación

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A NON-INTRUSIVE APPLIANCE LOAD MONITORING SYSTEM FOR IDENTIFYING KITCHEN ACTIVITIES

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Resumen

El objetivo de este proyecto consiste en desarrollar tecnologías que faciliten la independencia de las personas mayores así como la de personas con algún tipo de discapacidad. Más concretamente, se pretende incrementar la seguridad dentro de la cocina mediante la monitorización de los distintos eventos del equipamiento eléctrico.

La cocina es un lugar importante para el seguimiento de las actividades y la asistencia. Problemas en este área pueden causar consecuencias directas tales como incendios o fugas de agua. Pero este seguimiento puede revelar también actividades humanas tales como comidas olvidadas o electrodomésticos aún encendidos.

Las actividades de cocina están generalmente relacionadas con algún electrodoméstico. Por tanto, si podemos averiguar qué dispositivo se está usando, podemos determinar qué actividad se está desarrollando. Con este propósito, la implementación de un sistema de monitorización no intrusivo de cargas de dispositivos (Non-Intrusive Appliance Load Monitoring System o NIALMS) se describe en este documento.

NIALMS detecta los eventos del equipamiento eléctrico analizando la demanda total de carga mediante un único medidor de potencia eléctrica. Esto es posible debido a que los dispositivos presentan características especiales en los momentos de conexión y desconexión. Estas características consisten en cambios tanto positivos como negativos en las potencias activa y reactiva. Como dichas características son únicas para cada dispositivo, es posible reconocer el perfil de cada uno de ellos. Es decir, todo dispositivo puede ser identificado con una firma.

La identificación de los dispositivos se lleva a cabo mediante la implementación de algoritmos que procesan la información proveniente del medidor eléctrico. El sistema NIALM propuesto en este trabajo se basa en el análisis de conglomerados, que consiste en una interpretación gráfica para analizar firmas en estado estacionario.

Usando un medidor de potencia inteligente, una amplia serie de mediciones fue realizada en distintos electrodomésticos con el fin de adquirir los datos necesarios para la definición de las firmas. Una vez definidas, fue posible monitorizar los eventos provenientes del equipamiento eléctrico de forma remota mediante el sistema de monitoreo web desarrollado.

Palabras Clave

NIALMS, no intrusivo, monitorización remota, actividades de cocina, firmas de dispositivos.

Abstract

The aim of this work is to develop technologies that facilitate the indepence of the elderly as well as people with disabilities. Specifically, it aims to increase safety in the kitchen by monitoring the various events of electrical equipment.

The kitchen is an important place for activities monitoring and assistance. Problems in this area can be of direct consequences such as fires or water leakages. Howerver, activity monitoring can also reveal human's activities such as meals forgotten or left on appliances.

Kitchen activities are in general related to appliances. Therefore, if we can figure out which appliance is being used, we can determine which activity is taking place. With that purpose the implementation of a Non-Intrusive Appliance Load Monitoring System (NIALMS) is described in this document.

NIALMS detects events from electrical equipment by analyzing the total load demand with a single electricity power meter device. This is possible because electrical devices present special electrical characteristics during connection and disconnection. These characteristics consist of both positive and negative changes in the active and reactive power. Since these characteristics are unique to each device, it is possible to recognize the profile of each. In other words, every device can be identified by a signature.

Appliance identification is carried out by the implemented algorithms that process information from the electricity meter. The NIALM system proposed in this work is based on cluster analysis, which consists of a graphical interpretation to analyze steady-state signatures.

Using a smart power meter, an extensive series of measurements were performed on different kitchen appliances in order to acquire the necessary data to define the signatures. Once defined, it was possible to monitor the various events of electrical equipment remotly with the web monitoring system developed.

Key words

NIALMS, non-intrusive, remote monitoring, kitchen activities, appliance signatures.

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"*El agradecimiento es la memoria del corazón*"

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Symbols and Abbreviations

$\boldsymbol{\Delta T}$	Rising time or drop time
$\boldsymbol{P\_L_i}$	Total active power for phase i
$\boldsymbol{Q\_L_i}$	Total reactive power for phase i
$\boldsymbol{dP\_L_i}$	Difference between after-event and before-event active power values
$\boldsymbol{dQ\_L_i}$	Difference between after-event and before-event reactive power values
$\boldsymbol{U\_L}$	RMS voltage
$\boldsymbol{f}$	Electric power frequency
$\boldsymbol{R}$	Resistance
$\boldsymbol{X}$	Reactance
$\boldsymbol{Z}$	Impedance
$\boldsymbol{P}$	Total active power
$\boldsymbol{Q}$	Total reactive power
$\boldsymbol{S}$	Total apparent power
$\boldsymbol{V}$	Electric voltage
$\boldsymbol{I}$	Electric current
$\boldsymbol{V_{AC}}$	AC voltage
$\boldsymbol{I_{AC}}$	AC current
$\boldsymbol{P_{AC}}$	AC power
$\boldsymbol{V_{peak}}$	Peak voltage
$\boldsymbol{I_{peak}}$	Peak current
$\boldsymbol{P_{peak}}$	Peak power
$\boldsymbol{V_{rms}}$	RMS voltage
$\boldsymbol{I_{rms}}$	RMS current
$\boldsymbol{I_{1,rms}}$	RMS original current

A	Amps
AARP	American Association of Retired Persons
AC	Alternating Current
ADL	Activities of Daily Living
ALF	Assisted Living Facilities
BT	Basic Testing
CSIC	Consejo Superior de Investigaciones Cientificas
DC	Direct Current
DEM	Documentation, Evaluation, and Memory report
DIEM-BA	Devices and Interoperability EcosysteM - Building Automation
DPF	Distortion Power Factor
DRY	Don't Repeat Yourself
EU	European Union
eQL	Electricity Quality and Load
EPRI	Electric Power Research Institute
GSM	Global System for Mobile Communications
GUI	Graphical User Interface

HTML	HyperText Markup Language
HTTP	HyperText Transfer Protocol
IADL	Instrumental Activities of Daily Living
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IP	Internet Protocol
LT	Lab Testing
MIDE	Multi-disciplinary Institute of Digitalization and Energy
MIT	Massachusets Institute of Technology
MTV	Models, Templates, and Views
NIALM	Non-Intrusive Appliance Load Monitoring
NIALMS	Non-Intrusive Appliance Load Monitoring System
PC	Personal Computer
PF	Power Factor
RMS	Root Mean Square
SI	International System of Units
SMS	Short Message Service
SPEED	Single Point End-use Energy Disaggregation
TP	Training Process
THD	Total Harmonic Distortion
UI	User Interface
URL	Uniform Resource Locator
USA	United States of America
V	Volts
VA	Volt-Ampere
VAr	Volt-Ampere reactive
W	Watts

Preface

The work described in this Final Project was performed in the Department of Automation and Systems Technology of Aalto University (Finland) during the second semester of the course 2010-2011.

It is noteworthy to mention that this work belongs to the MIDE Ylämummo project where the acronym MIDE means Multi-disciplinary Institute of Digitalization and Energy. The MIDE project, which is funded by Aalto University and composed mainly of students, aims to develop integrated systems for Assistive Automation in elderly care with mobility and safety purposes.

In addition, this project works closely with the DIEM-BA programme (Devices and Interoperability EcosysteM - Building Automation) which has been designed to facilitate interoperability between different domains and applications.

1
Introduction

1.1 Project Motivation

We live in an era marked by an unprecedented aging. A study on aging established by CSIC General Foundation says that about 30% of the Spanish population will be over 65 by 2050 [1]. This demographic phenomena is affecting the entire globe and will have a significant impact on health and pension systems in many countries.

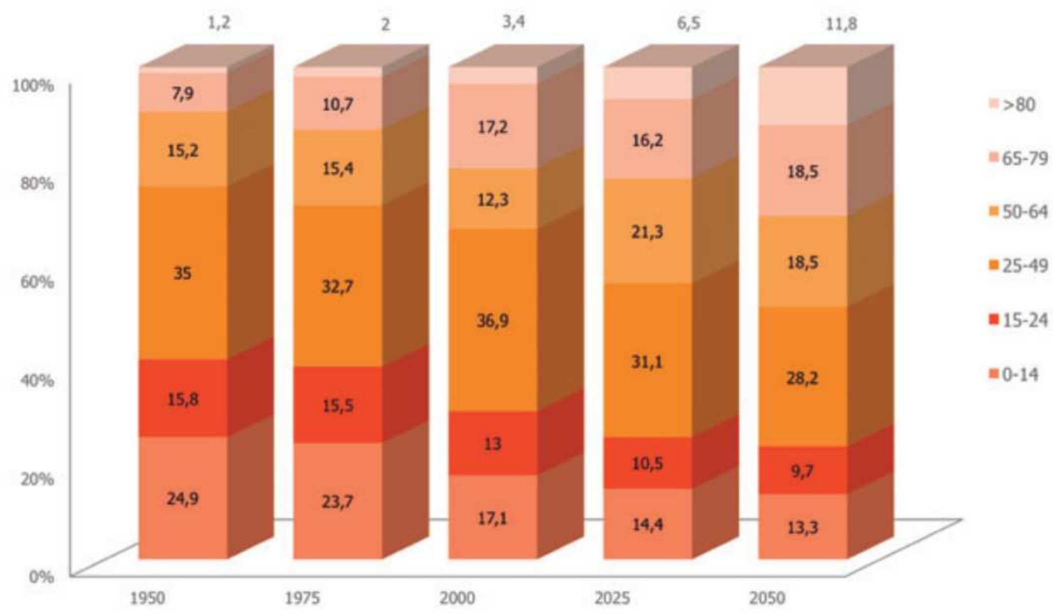

Figure 1.1: Estimated population groups in the EU 25 between 1950-2050 [1]

This situation has two major impacts on society: the decreasing proportion of working people and the increasing population which require much more care. In other words, the ratio of workers to retirees is dropping over the years. As a consequence, it is necessary to provide adequate services for the elderly in order to ensure their welfare.

Different studies assert that living independently is often the choice of the elderly people. For example, the AARP (American Association of Retired Persons) reported in July 2010 that eighty-eight percent of Americans over 65 years old want to stay as long as possible in their current houses [11].

Table 1.1: People who would like to stay in their current residences for as long as possible [11]

Opinion	**Age**			**Gender**	
	45-49 n=109	**50-64 n=542**	**65+ n=334**	**Male n=466**	**Female n=519**
Strongly or somewhat agree	81%	85%	88%	81%	89%
Strongly agree	60%	72%	78%	69%	76%
Somewhat agree	21%	13%	10%	12%	13%

As a result, the **Aging in Place** concept attempts to delay the relocation of the elderly by enabling them to live independently for as long as possible in a confident and comfortable way. This implies to ensure the necessary support to cover their changing needs by adding care services at their own residences [13].

Although health systems of many countries are usually willing to spend high amounts of money to keep seniors citizens institutionalized for a lifetime, they seem unwilling to cover adequate home care (which is usually a more affordable and desired option).

However, a study realized in 2001 by Harvard University [2] declares that health and housing are interrelated: *"When a living environment is affordable and appropriate, an aging individual is more likely to remain healthy and independent"*.

Care systems must reflect this relationship between health and housing avoiding inefficiencies in the elderly care due to the provision of both undercare and overcare. These inefficiencies may cause problems and increase expenses. For that reason, services and facilities must be designed to fit the needs of the individual rather than matching an individual to an existing service or facility[2].

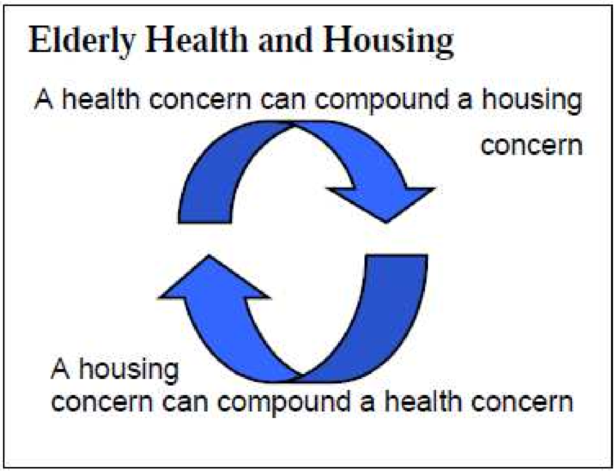

Figure 1.2: Circular relationship between elderly health and housing [2]

The motivation of this project is therefore to develop technologies that facilitate the independence of those who need special attention, like older citizens or people with disabilities. More specifically, it aims to increase safety in the kitchen by monitoring the various events of electrical equipment.

Towards that goal, we propose a monitoring system that is able to show which kitchen appliances are being turned on and off. This method can help people with memory disorders by implementing a warning system designed to support home care. That is, a system that alerts the user when a device has been on for too long or which appliances are still on when leaving the house.

In addition, since the data will be accessible from a web browser, it is also possible to follow the daily activities of a person remotely. For example, the system would show how many times the person has cooked or has prepared coffee in a day. This information can be helpful for nurses or relatives in charge. Receiving more information could relieve their worries and at the same time prevent or identify health problems (e.g. insomnia noticed from uncommon behaviour) [14].

1.2 Goals

The main target of this project is to develop an activity monitoring system capable of identifying electrical appliances events. In other words, when the appliances are being turning on and off. With that purpose, a NIALM system (Non-Intrusive Appliance Load Monitoring System) has been implemented. Its special requirement is that electrical events are detected at a single point.

To achieve the expected goal it is necessary to measure the features of the various electrical devices in order to create a database. Thereafter, it will be possible to differentiate the appliances and determine their current status. The idea is to relate kitchen activities with appliances. As devices can be distinguished by their electrical behaviour, the user will be able to determine which activity is being performed.

Extraction of the electrical features was performed by way of a smart power meter and processed by implemented programming algorithms. Python programming language and Django web development environment were used in a Linux machine in order to implement the work and to allow easier future development. A description of these software and hardware tools will be detailed in Chapter 4.2.

Furthermore, since this work is part of the DIEM - BA project designed to facilitate interoperability between different kind of systems, this work will be integrated in a higher level existing platform called ThereGate. Although the implementation will not be contemplated in this report (because it just consists of adding a few lines more of Python code), a brief description of the platform will also be detailed in Chapter 4.2.

1.3 Description of Work Progress

The development of the prototype performed in this Final Project was conducted in Aalto University (Finland). This development can be divided into the following stages:

1. **Training Process:**

   This was the starting point of the project where the goals were defined. To accomplish those objectives, it was necessary to acquire basic knowledge by reading and collecting documentation related with NIALMS and Assistive Automation.

   The material of the project was also chosen and acquired at this stage. Meanwhile, a learning process in Python programming language and Django management was carried out by following the official documentation from the web.

2. **Basic Testing:**

   The purpose of this stage was to develop the database administration, the program, and the user interface in order to prove that it was possible to achieve the expected results.

   To make it simple all the activities concerning this phase were realized in the workplace, reducing the meter installation to one single electrical input. Besides, only a coffee maker and a lamp were used as testing devices.

3. **Lab Testing:**

   The aim of the project is to obtain a practical implementation of a monitoring system for identifying kitchen activities. This part was more challenging as it applied to the department's kitchen the work developed in the basic testing.

   This stage was just the evolution of the previous one meaning that improvements in the database administration, algorithms, and user interface were done. The main difference between both stages was that this one pays more attention in the device identification algorithms, while the previous one was more focused on the development of the system. Besides, the implementation of the system in the ThereGate platform was done.

4. **Documentation, Evaluation, and Memory Report:**

   This stage was developed throughout the project although it becomes more relevant as the project progressed. It included reading and collecting documentation, evaluation of the work, and realization of the memory report.

   In addition to these activities, a meeting and a report were realized every week along the life of the work to discuss progress, approaches, and solutions.

The previous tasks are represented in the Gantt diagram of Figure 1.3. The red color shows each of the four stages already described, while blue color shows the activities that comprises those stages.

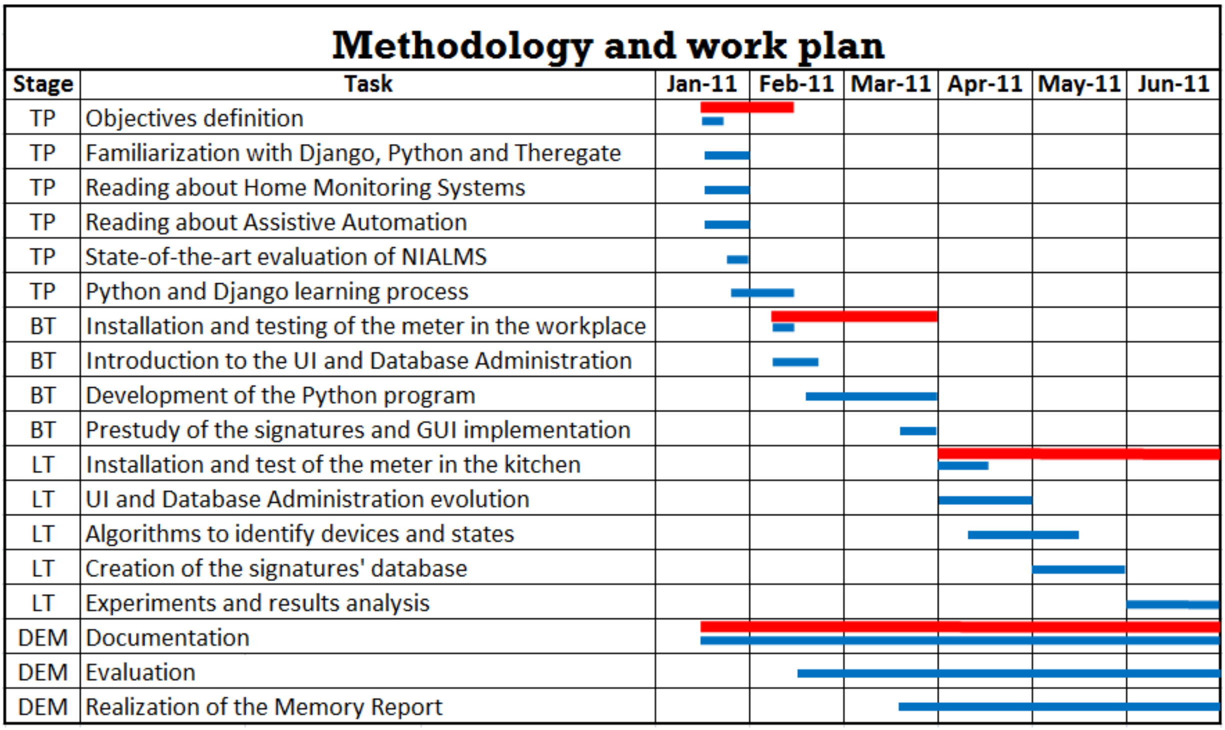

Figure 1.3: Methodology and work plan presented in a Gantt diagram

1.4 Document Structure

This document is structured as follows:

- **Chapter 1: Introduction**

  This chapter presents the motivation, objectives, and structure of this document. As the project has been done abroad, a description of the work progress is also included in this chapter.

- **Chapter 2: Monitoring People's Activities**

  In this chapter, the basic daily activities are described introducing concepts such as Assisted Living and Assisted Living Facilities. It also explains why the kitchen environment has been chosen for this monitoring system and which kind of electrical appliances can be found there.

  In addition, an overview about remote monitoring has been done highlighting its advantages and reasons why it has been used in this project.

- **Chapter 3: NIALMS**

  A introduction to NIALMS is described including its background, different applications, and characteristics.

- **Chapter 4: System Design and Implementation**

  The design and implementation of this work are described in this chapter. It includes the algorithms, database administration, user interface, and meter issues.

  Besides, this chapter describes the hardware and software tools used in both monitoring and recording systems that make up this project.

- **Chapter 5: Tests and Results**

  This chapter presents the experimental results for the basic and lab tests. Signatures of each appliance are represented here as well as an overview of their operation system.

- **Chapter 6: Conclusions and Future Work**

  This final chapter summarizes the main achievements of the work, discusses the obtained results, and provides suggestions for future work.

A short glossary has been included after the last chapter in order to make a brief explanation of some important concepts which appear in this report.

2

Monitoring People's Activities

2.1 Day to Day Activities

Medical professionals believe that it is possible to detect emerging physical and mental health problems by analyzing changes in human behaviour through their daily routines [15]. In general, day to day activities are things people do on a regular or routinely basis. These activities can be grouped into [16] [17] [12] [18]:

- **Activities of Daily Living**

  The term Activities of Daily Living or ADLs refers to the basic tasks that people do everyday without needing assistance. These activities are required for personal self-care and independent living. The most important are: eating, dressing, toileting, bathing, and moving.

- **Instrumental Activities of Daily Living**

  The term Instrumental Activities of Daily Living or IADLs refers to tasks that may not need to be done everyday but are also important for living independently. IADLs include domestic and community tasks such as shopping, using the telephone, cleaning, operating electronic appliances, or handling budgets.

Table 2.1: Basic ADLs and IADLs [12]

ADLs	**IADLs**
Eating	Using the telephone
Continence	Shopping
Moving	Preparing food
Toileting	Housekeeping
Dressing	Doing laundry
Bathing	Using transportation
	Handling medications
	Handling finances

Whenever a person is unable to perform any of these activities, assistance is required. However, this assistance does not necessary mean 24 hour medical care in all cases. As a result, **Assisted Living** has emerged as a care alternative for those whom independent living is no longer possible.

Although a person of any age may have problems performing these activities prevalence rates are much higher for the elderly, who are the targeted audience of this project.

Assisted Living promotes independent and dignified living by ensuring health, safety, and well-being. It provides **Assisted Living Facilities** (ALFs) in order to supervise and assist with the day to day activities.

In this project, an ALF is developed. As mentioned, it consists of a monitoring system that provides objective data to help determine which care and assistance are required. In addition, it aims to prevent incidents by informing the user if some appliance has been on for too long. The system's strength is that monitoring can be achieved automatically without placing requirements on the subject.

2.1.1 Daily Living Scale

The independent living skills can be measured. These evaluations are useful not only to determine activity limitations or to provide an overview of functional status, but also to establish a baseline for treatment or measure outcomes of rehabilitation [18].

As an example, **Katz Index of ADLs** evaluates the degree of independence of a person by counting points according to the abilities or disabilities to perform the six basic ADLs [16].

A more appropriate instrument to assess independent living skills is the **Lawton IADLs Scale**. It was developed by Lawton and Brody in 1969 and like Katz Index of ADLs, it counts points to evaluate the degree of independence of a certain person [12].

The strength of Lawton Scale is that, while Katz Index makes a boolean decision about whether a person is able to live independently or not, Lawton Scale determines the degree of disability by defining different levels.

The Lawton IADL scale is applied in eight different domains shown in Table 2.1. As this project involves kitchen activities, the food preparation domain will be emphasized. Table 2.2 shows the four different grades of ability in which this IADL is divided.

Table 2.2: Grades of ability in food preparation

Degree of independence	**Needs required**
Plans, prepares, and serves adequate meals independently	No extra care
Prepares adequate meals if supplied with ingredients	Shopping assistance
Heats, serves, and prepares meals or prepares meals but does not maintain adequate diet	Special attention
Needs to have meals prepared and served	External assistance

Monitoring kitchen activities can help to detect problems also in food preparation. If the system does not monitor any activity from cooking appliances such as microwave oven or kitchen stove for a long time, assistance is required. This situation reflects either that the person needs to be supplied with food or that the individual is unable to eat without help.

2.2 Kitchen Activities

As mentioned, this project is focused in the kitchen environment. The kitchen is often referred to as the *"heart of the house"*. The reason for this nickname is that it is not only a place for cooking but also eating and gathering around the table for good conversation. As a consecuence, it has become the focal point for numerous home automation projects not only with the aim of increasing comfort but also safety and energy management.

Appliances and kitchen activities are interrelated. For example, the washing machine is used when doing the laundry, and the microwave oven when heating food. Therefore, if it is possible to know which appliances are being used at a given time, it is then possible to identify which activities are taking place.

The aim of this work is to take advantage of this feature with the purpose of increasing kitchen safety for senior citizens by monitoring kitchen activities. This experimentation include activities such as brewing coffee, boiling water, washing the dishes, or cooking food. The activity recognition is determined by a single factor: electrical appliance signatures.

2.2.1 Equipment

Home appliances make our lifes easier. They can be classfied according to criteria such as size, function, type of output energy, etc. However, in this case it is necessary to classify them according to electrical characteristics.

By analyzing the voltage and current signals of the different appliances in operation, it is possible to assert that electrical equipment is identificable by a certain number of parameters. These parameters consist of duration and shape of the current transient in the moments of connection along with power values and current harmonics.

In the article "Using appliance signatures for monitoring residential loads at meter panel level" extracted from the IEEE, six different groups of devices are described depending on their different electrical behaviours [19]:

- **Resistive Appliances**

  As results in Chapter 5 will show, most kitchen devices are resistive. Some examples included in this group are heating appliances or incandescent lighting.

  The main element in this type of devices is a resistor. As these appliances consume only real power, they are characterized by a zero reactive power. On the other hand, they do not present current harmonics components and their transient when switching on is null or very short.

- **Pump Operated Appliances**

  These devices have electric motors driving a pump, including appliances such as refrigerators, freezers, or washing machines. Pump operated appliances are generally characterized by a substantial reactive power, an odd-numbered harmonic current, and a long transient when switching on.

- **Motor-driven Appliances**

  This category involves appliances containing an electric motor such as fans or mixers. The difference between this group and the pump operated group lies in lower switching on transients.

- **Electronically-fed Appliances**

  Low power consumption appliances are grouped in this category. They are characterizad by a high amplitude switching on transient and a current spectrum rich in harmonic components. Televisions, video-recorders, or personal computers are some examples which belong to this group.

- **Electronic Power Control Appliances**

  The identification of this kind of devices is generally quite difficult. This group includes appliances which characteristics generally vary with the power level at which they operate such as halogen lights, some vacuum cleaners, or some cookers.

- **Fluorescent Lighting**

  These light source is characterized by a substantial phase shift between current and voltage, a very high third harmonic of the current, and a long two-step switching on transient.

2.3 Monitoring

2.3.1 General Information

According to the Oxford English Dictionary, monitoring is to observe, supervise, or keep under review; to measure or test at intervals, especially for the purpose of regulation or control.

In this project, a monitoring system has been developed in order to improve elderly life conditions at home. The monitoring can be divided into two different levels:

- **Self Monitoring:** The user will be able to see which appliances are still on.
- **External Monitoring:** The caregivers will be able to follow the person's activities.

Table 2.3 shows the tasks that are usually involved with monitoring systems and their relationship with NIALMS. A farther description of NIALMS' tasks will be explained throughout the following chapters.

Table 2.3: Monitoring systems tasks' and their relationship with NIALMS

Task	**Relationship with NIALMS**
Establishing indicators	Indicators are changes on power consumption
Setting up systems to collect information relating to these indicators	NIALM system based in a power meter
Collecting and recording the information	The events will be recorded by the power meter
Analysing the information	Users will evaluate the information collected by analysis of the algorithms

2.3.2 Remote Monitoring

Overview

The emergence and expansion of the Internet has opened up entirely new opportunities for monitoring systems. Remote monitoring using Internet is easy, fast, and inexpensive. Thus, it is used in several fields such as security, business, or bank management.

Remote monitoring is also very suitable for Home Automation applications. It will allow people to be immediatly informed about problems or events that occur at home, and even to interact with home systems remotely.

The only requirement for using remote monitoring is to have a device supporting the HTTP protocol. Thanks to wireless communications there is a large number of devices that can be used as monitoring stations, for example mobile phones, tablet PCs, or laptops. The interface between the system and the user can be displayed by any web browser simply by providing the system's Internet address or URL.

A website is a collection of related web pages containing images, videos, or other digital data. In monitoring systems, websites are usually dynamic meaning that they are updated automatically and frequently based on certain criteria. Moreover, it is also possible to notify the user about the system status via email or SMS.

Although remote monitoring implies instant set-up and immediate results for the user, it is important to take into account possible privacy concerns from the begining.

Advantages

Nowadays, remote monitoring is used in many applications as there are benefits for both users and service providers. These benefits can be divided into three groups:

- **Accessibility:**

  Websites are accessible anytime anyplace. That means that every feature of the application is available on demand anywhere in the world. Moreover, as the Internet provides real-time content, a quick and accurate diagnosis of the information is possible. The only requirement for the user is to have a device providing Internet access. Therefore, there are no integration issues and no technology risk.

- **Usability:**

  The end-user is free to choose the most convenient monitoring device and web browser. Thus, the ease of use and learnability of the system is determined by the monitoring application which is usually intuitive. This means that no technical experience or training are needed.

- **Cost:**

  As remote monitoring is reachable from any browser, it requires zero capital investment meaning that there is no need to buy, install, or support any specific software or hardware. On the other hand as the system is scalable, it can easily handle growing applications without extra cost.

3
NIALMS

3.1 Introduction

There are two different types of load monitoring systems: intrusive and non-intrusive [20] [21] [3] [4].

The most common monitoring system is the **intrusive**, where multiple sensors measure the power consumption of each appliance. As this method requires multiple sensors in order to monitor the different appliances, it imposes costs and a complex installation which usually requires wiring and data storage centers.

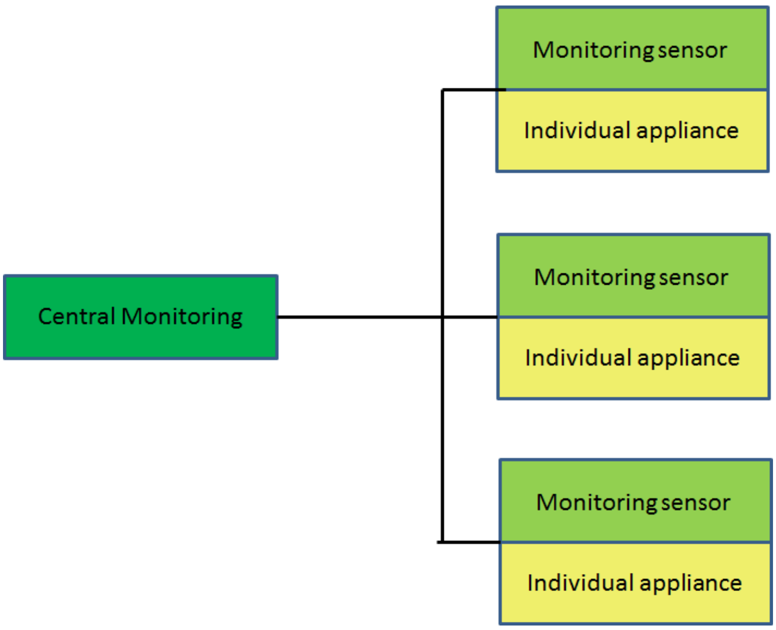

Figure 3.1: Intrusive monitoring systems [3]

Non-intrusive systems on the contrary, do not require to intrude into an appliance when measuring its power consumption. Since this monitoring system presents significant advantages in terms of cost and convenience, it has been chosen for the development of this work.

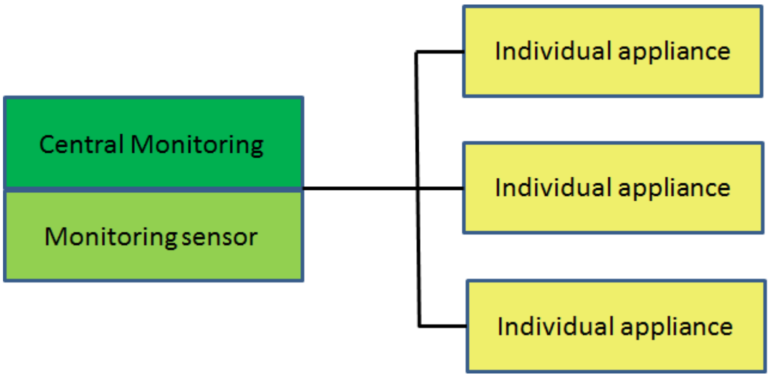

Figure 3.2: Non-intrusive monitoring systems [3]

3.1.1 Background

Non-intrusive Appliance Load Monitoring System (NIALMS) is a recent method to estimate load profiles of individual electrical devices by collecting and disseminating the power-draw information [22]. It was originally developed in 1982 by the Massachusets Institute of Technology (USA). The idea started when the professor **George W. Hart** was collecting and analyzing load data as part of a residential photo-voltaic systems study [5].

Figure 3.3: George W. Hart

After measuring the electricity consumption of homes, Hart discovered that it was possible to analyze the obtained results to tell what was happening in the monitoring homes. As a result, the professor and the MIT Energy Laboratory Staff realized that this kind of system could have significant value to utilities [20].

The Electric Power Research Institute (EPRI) has sponsored NALMS research since its origin. EPRI chose Telog Instruments to commercialize the NIALMS into a research tool available to electric utilities. First commercial product was developed in the United States at the end of last century. However, several research and development projects have been performed along the years in many countries such as Japan, France, Finland, or Denmark [20].

Strategies for non-intrusive monitoring have been developed over the years. Nowadays, the most expanded product on the market is SPEED (Single Point End-use Energy Disaggregation) developed by the American company Enetics.

3.1.2 Applications

Although this project is an example of a Non-Instrusive Monitoring System applied to Assistive and Home Automation, NIALMS can be also used in different fields from residential to industrial. Some examples of these applications are [5]:

- **Energy Management:**

  NIALMS can be used to give feedback on energy usage in order to reduce electricity bills. As an example, the system can be temporarily installed at the customer's house in order to analyze the characteristics of the appliances and how electricity is used. After some time, it would be possible to suggest how to reduce consumption and costs.

- **Load Forecast:**

  It is possible to estimate future energy demands by a continuous analysis of the power consumption. This will optimize the energy production implying savings for the power suppliers. In addition, it will help planning transmission and distribution infraestructures.

- **System Failures:**

  NIALMS allows to reveal system failures by detecting unusual information from the electrical consumption behaviour. Therefore, it can be used in security control applications such as failure of monitoring devices.

3.2 Characteristics

Unlike ordinary systems where complex hardware is used in order to monitor the different appliances, NIALMS can distinguish electrical appliances by analyzing the total load demand at a single location. As a consecuence, NIALMS state of art is divided into two: a recording system that detects the events from the electrical equipment, and load identification algorithms in order to recognize the operating devices. Figure 3.4 represents the NIALMS data flow conducted by the recording system and the identification algorithms.

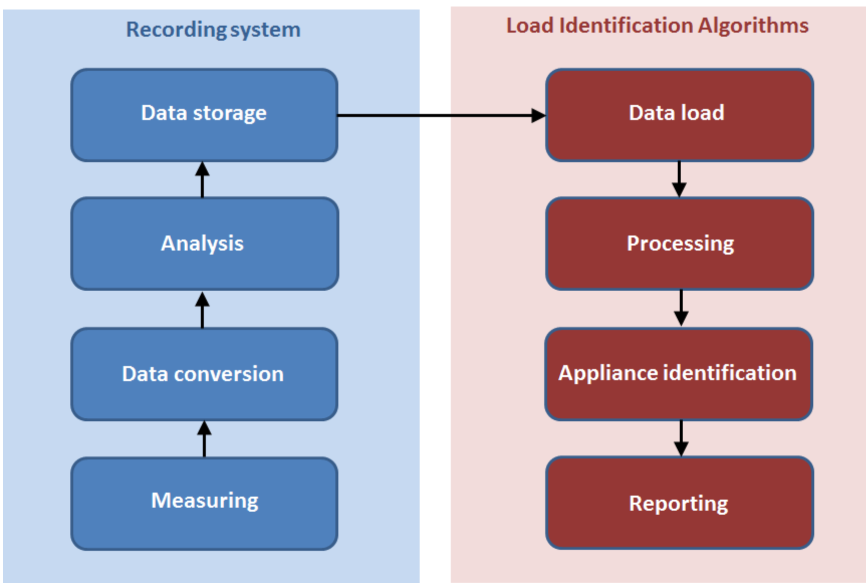

Figure 3.4: NIALMS data flow

NIALMS is based on the fact that electrical equipment show special characteristics in the moments of connection and disconnection. In the analysis conducted in this project, these characteristics consist of positive and negative changes in the real and reactive power. Before delving into how the system works, it can be useful to get familiar with some simple electrical concepts. More documentation about this can be found in Annex B.

Anything that uses electricity is referred to as an electrical load. As a consecuence, standard household appliances are AC loads and therefore, they can be divided into three different gorups: resistive, inductive, and capacitive. In purely resistive loads, the power is always positive meaning that it will always supply the load. However, for purely reactive loads the power is bidirectional as it flows from the source to the load and vice versa.

As a result, the power is divided into two: active power (P) consumed by resistive loads, and reactive power (Q) consumed by inductive and capacitive loads. A thrid type of power appears when adding the vectors P and Q. It is refered to as apparent power (S) and it represents the total power required by the load.

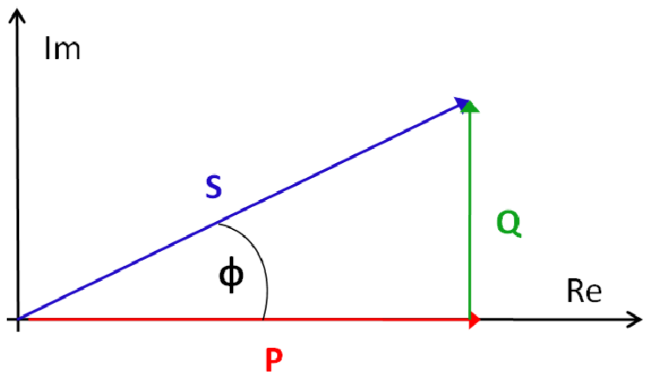

Figure 3.5: Power triangle relating the three types of power

As seen in Figure 3.5, a new parameter can be derived from the definition of the three powers. This parameter is the cosine of the angle between real and apparent powers, and it is refered to as power factor. The angle (ϕ) indicates the proportion of power transformed into useful work (P) from the total power (S) required by the load. Therefore, power factor is a measure of how efficiently or inefficiently electrical power is used.

In purely resistive loads, as there is no reactive power the cosine is maximun (PF = 1). However, for purely reactive loads such as inductors or condensators, the power factor is zero as now the active power is null.

3.2.1 Recording System

The recording system consists of a quality power meter connected to the power supply. This meter will measure the electrical signals and convert them into evaluable parameters (digital data). The communication chanel is the house wiring.

By using mathematical algorithms the meter will analyze changes in the power consumption. These changes will be stored in the meter's memory so that they can be used by the load identification algorithms. Before going further with the identification process some terms should be explained.

Appliance Signatures

As human's signatures, each electrical device contains unique features in its consumption behaviour [4] (Figure 3.6).

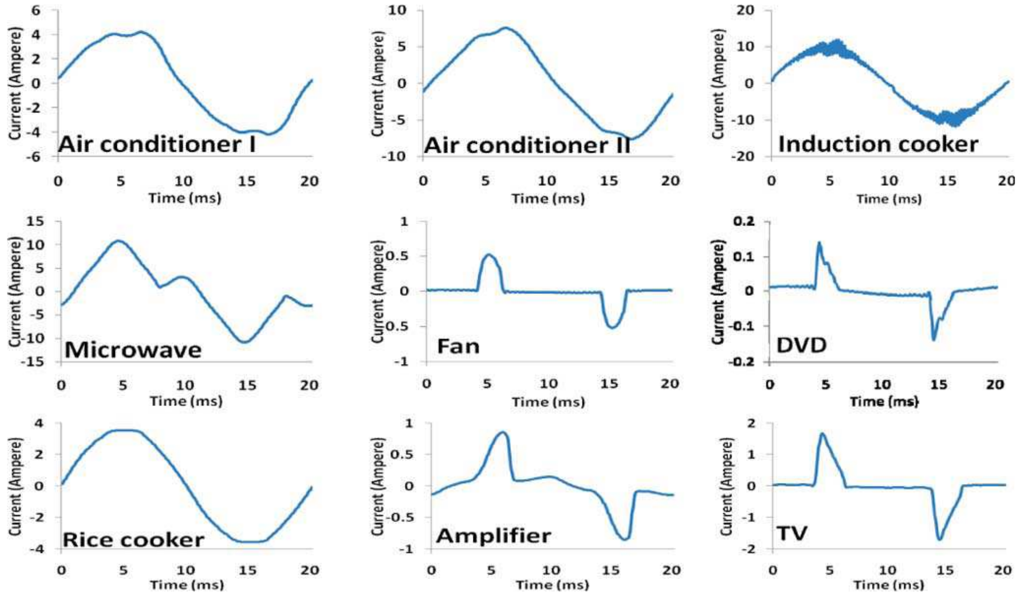

Figure 3.6: Examples of different current signatures [4]

An appliance signature, also refered to as **fingerprint**, can be defined as a measurable parameter of the total load that gives information about the nature and operating status of an individual appliance [5].

Signatures can be also divided into intrusive, if the measuring process requires entering into the appliance; and non-intrusive, if it is possible to measure the electricity consumption of an appliance by passive observation. Only the last ones are considered in this work.

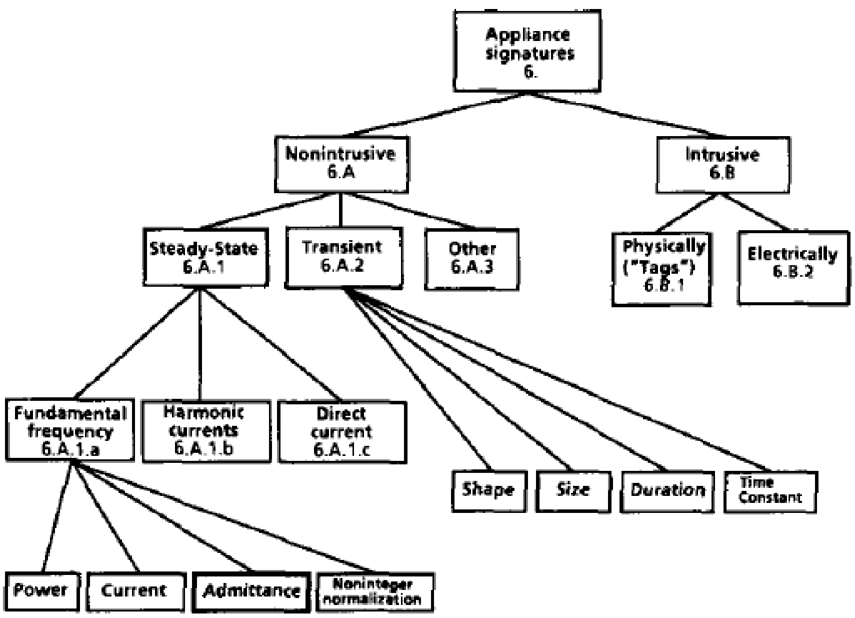

Figure 3.7: Signature Taxonomy [5]

There are two important subclasses within the non-intrusive signatures: steady-state signatures, if the information about the appliance state change is continuously present in the load as it operates; or transient signatures, when the information is briefly present during times of state transition [5].

- **Steady-state Signatures**

  Steady-state signatures derive from the difference between steady-state properties of operating states, calculated as the difference between the operating levels of the connected states [5].

  In other words, steady-state signatures are defined by the moments at which the corresponding measurements change from one state to another. These changes are characterized by a magnitude and a sign of active and reactive power, and they usually correspond to an appliance turning on or off.

  A step change in power of an appliance's operating state to another state is labeled as an **event**, and in an analogous way equipment able to detect these events is called an event recorder [20].

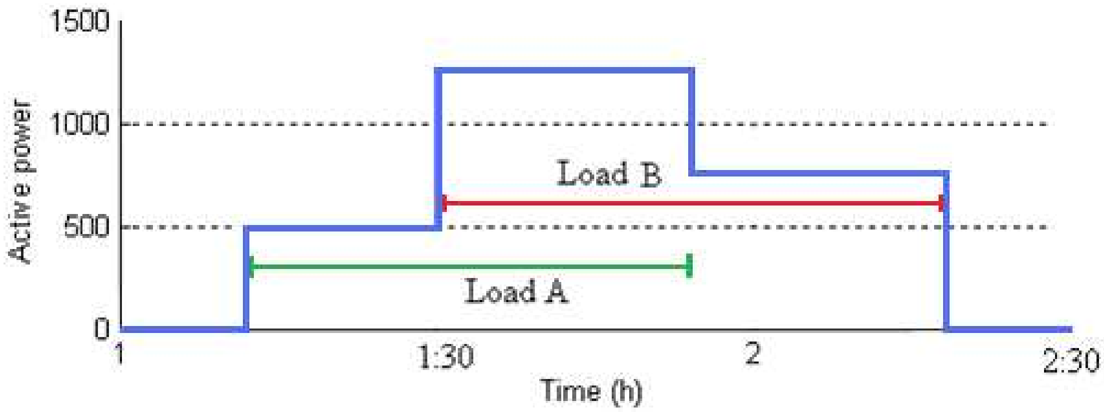

Figure 3.8: Active power changes during appliances operation [3]

- **Transient Signatures**

  The transient behavior of the appliances depends on the generating mechanism of the load. For example, the turn-on transients associated with a personal computer and with an incandescent lamp are distinct because charging capacitors in the computer power supply is fundamentally different from heating a lamp filament [23].

  The parameters that categorize transients are size, duration, time constants, or parametric variables in models which can be fit to the observed waveforms [20] [3] [5].

The proposed NIALM system relies only on steady-state signatures. As shown in Figure 3.7, these signatures can be divided into three categories: fundamental frequency, harmonic currents, and direct current. On one hand, there are no appliance of significant interest to utilities that has a substantial DC current flow [5]. On the other hand, recording harmonic frequency signatures requires more demanding equipment than the recording fundamental frequency signatures. As the power meter used in this work has a low sampling rate (100 ms), it is not possible to separate the signatures into harmonic frequencies [20]. Therefore, only fundamental frequency signatures are considered in this work.

There are several reasons to use steady-state signatures instead of transient signatures [5]:

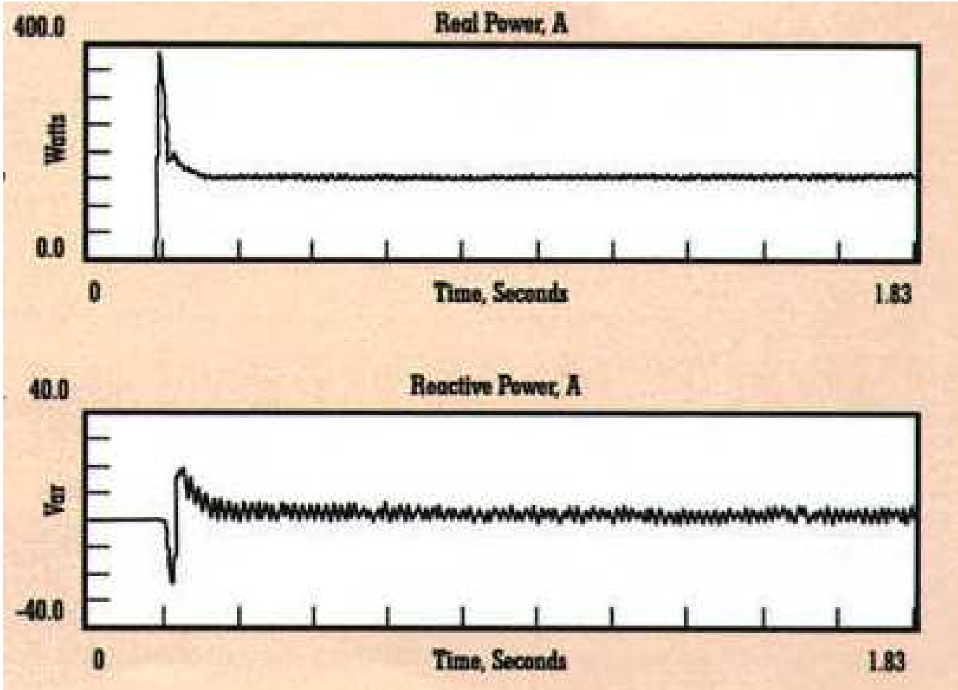

Figure 3.9: Example of an instant-start fluorescent lamp bank transient [6]

- Firstly, transient signatures are more difficult to detect than steady-state signatures as they measure a switching mode instead of a stabilized state. For this reason, transient analysis require a measurement device to a considerably higher sampling rate.

- The second advantage of steady-state over transient signatures is that turn-off events present fingerprints. In contrast, most appliances which generate a transient at turn-on generate no transient at turn-off. Thus, a detector for steady-state signatures provides information about a larger number of state changes than a detector for transients.

- Another important property of steady-state signatures is that they are arithmetically additive. For example, the simultaneous turning on of a 2 kW water boiler and turning off of a 200 W lamp result in a 1800 W step increase being detected in the total load. Therefore, the additivity of steady-state signatures allows simultaneous events to be properly analyzed.

- Finally, transient signatures provide less information than steady-state signatures because they are available for registration only the switch-on at the time. However, as they provide different information, they might be useful to identify appliances that exhibit similar steady-state behaviour.

As mentioned, steady-state signatures consist of changes in real and reactive power. Figure 3.10 represents an event detection carried by the meter. Switching an appliance on or off is generally done with other appliances already in operation. For that reason, identification is not linked to the current value but to its variation $(\delta P, \delta Q)$.

The meter samples both active and reactive power at a certain frequency. When an appliance change its status (e.g. from on to off), the meter detects a change in the power consumption and records it as an event. However, this change in power consumption has a tolerance condition: the system will ignore any change which is not sufficiently close to the current power consumption.

Sometimes two devices can change their status at the same time causing a unique power change, which can hinder the identification of the devices. For that reason, only a small number of appliances which are changing their status are expected.

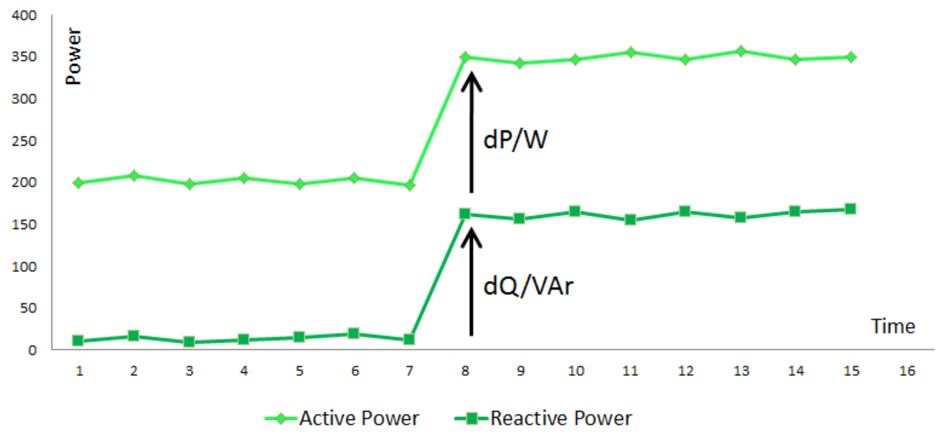

Figure 3.10: Event detection by the meter

3.2.2 Load Identification Algorithms

The load identification algorithms are carried out by a PC which must be connected to the meter in order to read the recorded measurements. There are different methods to process the data and recognize appliances. Some of them are [4] [24]:

- **Artificial Neuronal Networks:**

  Appliances are identified by analyzing the power consumption with the recognition ability of Artificial Neuronal Networks. This system adapts to the device's information collected during the learning process, solving paradigms that linear computing cannot solve.

- **Minimum Residue:**

  It solves the load identification problem by an optimization problem. The task of this method is to calculate the residues between the sample and the library of signatures. The appliance with minimun residue can be considered as the targeted solution. The complexity of this algorithm increases when the database gets larger.

- **Committee Decision Mechanism:**

  This method combines multiple algorithms such as Most Common Occurrence and Least Unified Residue in order to render the best appliance identification under a comittee decision mechanism. To do so, it might be necessary to collect different data in the load disaggregation process such as: active and reactive power, harmonics, instantaneous admittance waveform, instantaneous power waveform, eigenvalues, and switching-transient waveform.

- **Cluster Analysis**

  This method is based on the events caused by electrical appliances. These events consist of changes in the power consumption caused when devices are turn on and off. By plotting those changes in a two-dimensional space, it is possible to see that data from a single appliance tend to form clusters.

Appliance Models

In Chapter 2.2.1, electrical equipment was classified into five different groups according to electrical aspects. However, from the point of view of steady-state signatures appliances are divided into two groups [20] [5]:

- **Two-state Appliances**

  Appliances included in this category have a single transition power value ($\delta P, \delta Q$) between two power states (on/off). For that reason, this group is also refered to as on-off appliances. As Figure 3.11 shows, the value of the transition power is always equal to the one at the on-power state ($\delta P = P_{ON}, \delta Q = Q_{ON}$).

  Several household appliances such as toasters or lamps, are two-state appliances. In addition, some devices containing several independent loads can be also considered as a set of elements included in this group.

  As an example, dishwashers consist of a heating resistor and a motor to pump and circulate the water. Because all this loads switch on and off independently, it is possible to consider them as two-state appliances. As a result, they can be identified separately because they do not form transition powers which are combinations of each other.

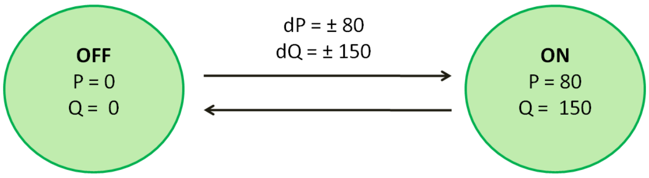

Figure 3.11: Two-state appliance model

- **Multi-state Appliances**

  Appliances with distinct types of on-states belong to this group. As seen in Figure 3.12, state powers are combinations of transition powers which makes much more difficult the analysis.

  Some devices have complicated models with multiple states interconnected. The kitchen stove for example, usually consists of several hot plates with different cook programs controlled manually or thermostatically.

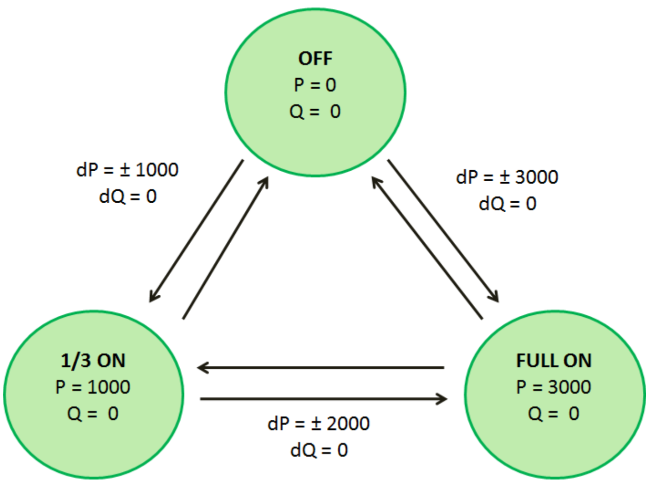

Figure 3.12: Multi-state appliance model

4

System Design and Implementation

4.1 Design

The aim of this project is the identification of the electrical appliances inside a kitchen environment. This work can be divided into four different parts:

1. **Feature Extraction**

   The power meter extracts different attributes such as active and reactive power from voltage and current waveforms in order to acquire the necessary data to make the analysis.

2. **Event Detection**

   When changes in the extracted parameters are detected, an event has happened. In this system, this task is also carried by the power meter.

3. **Appliance Identification**

   The extracted data gives important information for the appliances' identification. As seen in the previous chapter, there are different methods to process the data and recognize appliances. However, all of them involve a learning process of load characteristics. This task is carried out by a PC although it can also be handled by a home server (e.g. ThereGate).

4. **Monitoring**

   The event's information is shown to the user by the web application developed. Thus, this task can be handled by any device with Internet access.

The implementation of this work is focused in the two last parts, as the feature extraction and event detection are performed by the power meter provided.

Regarding the identification algorithms, cluster analysis has been used in order to reduce the complex data to a graphical interpretation. External software tools were needed to implement the application in the user interface (see Annex A.3).

4.1.1 Cluster Analysis

As mentioned in the previous chapters this method is based on the events caused by electrical appliances. Those events are changes in the consumption of active and reactive power caused when devices are turned on and off. As events from a single appliance tend to form clusters, the information can be graphically interpreted by a two-dimensional plot.

The plot represents the $\delta P, \delta Q$ plane in order to show the events. In addition, this representation allows to estimate the total power consumed (S) by the addition of the P and Q vectors.

As seen in Figure 4.1, on-events generally match off-events of approximately opposite magnitude. This means that possitive and negative events are usually symmetrical. Therefore, as on-events predominate in the first quadrant, off-events will do it in the third quadrant.

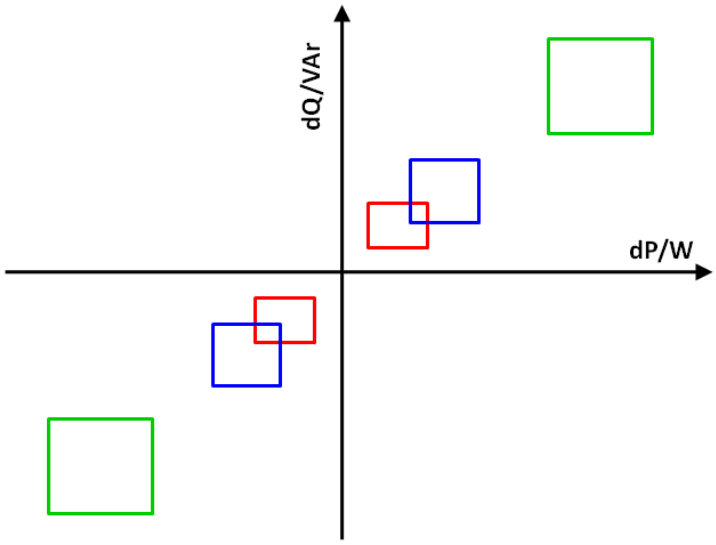

Figure 4.1: Events from a single appliance tend to form clusters in the plane δP,δQ

Clusters define devices' signatures. In this system, they are described by vertices of polygons surrounding those signatures. To proceed with the device identification, it is only necessary to check if an event belongs to an appliance's signature by prooving that the fingerprint is inside the polygon's area. To do so, a **Point in Polygon algorithm** is used.

The chosen Point in Polygon algorithm is based on the Jordan curve theorem which asserts that every Jordan curve divides the plane into an interior and exterior region [25].

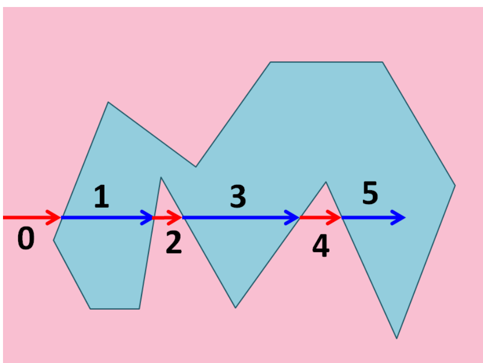

Figure 4.2: Point in Polygon demonstration

As Figure 4.2 shows, two-dimmensional polygons are by definition Jordan curves. To determine whether a point lies inside or outside the polygon is enough to count the number of intersections a horizontal ray make from outside the polygon to a certain point (x_p, y_p). If the number of intersections is odd, the point lies inside the polygon's area. Otherwise, the point does not belong to the polygon [26].

Actually, the algorithm used in this project starts with the premise that the point lies outside the area. Thereafter, it checks side by side if a horizontal ray starting from the point (x_p, y_p) to the right side has any intersection with the boundaries of the polygon. If there is an intersection, the algorithm refuses the initial premise and keep checking for more intersections (which will always refuse the current premise). Otherwise, the point will be outside the region.

The following function is responsible of the Point in Polygon algorithm. Its input arguments are the point to analyze dP, dQ, and the vertices of the polygon area stored in the vectors x, y. The output argument will be *True* if the point belongs to the polygon area. Otherwise, it will be *False*. In this case the boundaries of the polygon are considered in the outside region.

```
# Ref: http://www.ariel.com.au/a/python-point-int-poly.html

def PointInPolygon(x, y, dP, dQ):

    n = len(x)
    inside = False

    p1x = x[0]
    p1y = y[0]
    for i in range(n+1):
        p2x = x[i % n]
        p2y = y[i % n]
        if dQ > min(p1y,p2y):
            if dQ <= max(p1y,p2y):
                if dP <= max(p1x,p2x):
                    if p1y != p2y:
                        xinters = (dQ-p1y)*(p2x-p1x)/(p2y-p1y)+p1x # cross point
                    if p1x == p2x or dP <= xinters:
                        inside = not inside
        p1x,p1y = p2x,p2y

    return inside
```

4.2 Tecnologies for the System Implementation

4.2.1 Recording System

As mentioned, the change of power consumed when switching on or off a device can be measured and recorded. These changes are called events and can be detected by a control mechanism. In this project the eQL Monitoring Power Meter developed by the Finnish company MX Electrix Oy is used.

Electricity Quality and Load Meter

The eQL meter is an event recorder which provides significant opportunities for power and voltage measurement for each of the three electrical phases. Its applications make power quality reporting and monitoring easy.

Figure 4.3: Electricity Quality and Load meter

The technology used in the eQL meter consists of a microprocessor based energy meter with quality metering capability. It is possible to connect it to telephone or GSM network in order to read the events remotely [27].

This device, connected to the power supply (230V and 50Hz in Finland), can measure active, reactive, and apparent power for the three electrical phases. In addition, the measuring possibilities of the meter include voltage levels, distortions, interruptions, asymmetry, and zero components.

All measurements are stored automatically in different tables accesible by simple commands. The device can be connected to the PC both via Ethernet (RJ45 cable) or computer serial port (RS 232 connection). The reporting is based on the EN 50160 standard, which provides the limits and tolerances of various phenomena that can occur on the mains [28].

4.2.2 Monitoring System

The monitoring system consists of the load identification algorithms and the user interface. Its implementation has been developed by using the same technologies than the DIEM-BA project in order to keep the compatibility.

Python

The appliances recognition algorithms are developed in Python programming language. This high-level programming language is characterized by a clear and elegant syntax, which makes it a highly readable language.

Python ships with most Linux distributions, where it can be used from a terminal. However, it is a multi-platform programming language and it can be also used by development environments (e.g. Aptana Studio or Eclipse).

This programming language is often used as a scripting language for web applications as it permits a fast, flexible and easy web development [29].

Django

Django is an open source web framework developed in Pyhton which will be used to implement the user interface. Its main principle is DRY (Don't Repeat Yourself) which emphasizes the reusability of components.

Django aims to make common web development tasks fast and easy. This web framework is divided into two parts: an admin site and a public site. These parts consist of the following concepts:

- Models: a definition of Python classes in order to build the interrelations of a database.
- Templates: a description of how the data is presented to the user.
- Views: a processing request system that describes which data is presented to the user. They are the bridge between models and templates.

Because of those definitions it is said that Django has been referred to as an MTV framework [30].

ThereGate

As mentioned, this work is part of the DIEM-BA project which involves different home automation applications. In order to facilitate the interoperability between devices from different domains, ThereGate devices are used.

ThereGate is a home management platform similar to an ordinary network router that makes the underlaying technologies transparent to the application developer. This means that it unifies different technologies in order to present an easy understanding interface to the user [31].

Figure 4.4: ThereGate device

This solution, originally developed by Nokia and now supported by There Corporation, is based on an open Linux platform. It supports the most common smart home technologies, such as Z-Wave or ZigBee. However, the user can create own interfaces to incorporate other technologies to the system by defining new technology drivers.

4.3 Implementation

The implementation of the system based in the previous design, can be divided into four interrelated entities as Figure 4.5 shows:

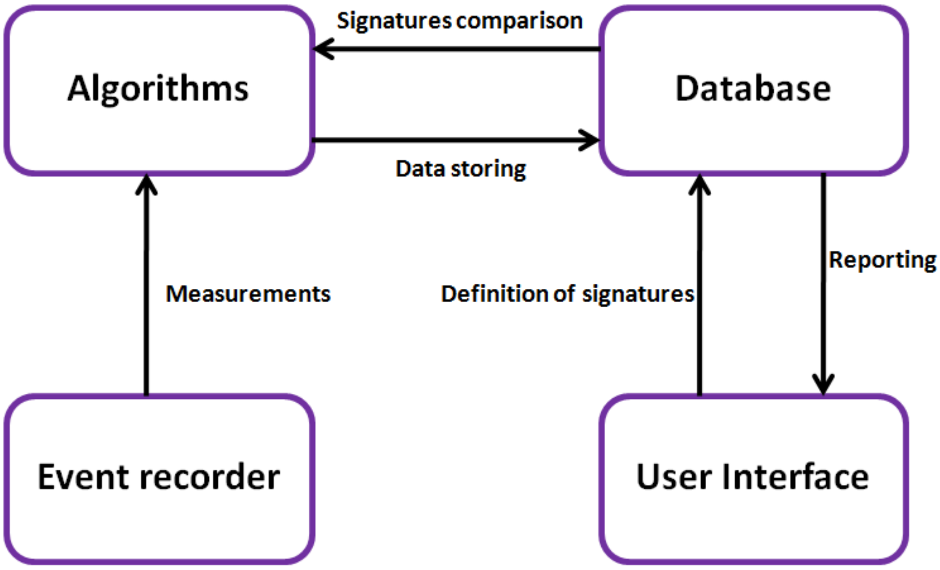

Figure 4.5: System implementation

The event recorder is responsible of the measurements which will be used by the algorithms in order to identificate an appliance. To do so, the algorithms need to compare the measurements with the signatures database, where the new information will be stored. Finally, the database will report the data to the public interface, where the user will be able to define new appliance signatures.

4.3.1 Event Recorder

The power analysis process is done by the eQL meter. This quality power meter has three different inputs to measure the power consumption of the three electrical phases.

In the experiment, each phase can handle 16 Amperes not to blow the fuses. As the mains use 230 V, it corresponds to 3.68 KW. In order to handle more power per phase, it is also possible to connect a single phase to multiple inputs. This is desiderable in the department's kitchen, where all the wires have the same electrical phase and 3.68 KW are not enough for the required purpose. As a result, the maximun load supported is 11.04 KW by connecting the same phase to all the inputs of the system.

The eQL meter, saves the event's data in different tables which are accessible by simple commands. The tables used in this work are:

- **Fingerprint Table**

  All the events recorded by the meter are stored here (fp_table). The parameters which define those events are described in Table 4.1, where the subindex i refers to one of the three meter's inputs.

- **Measurement Table:**

  Every ten minutes the meter saves different parameters automatically in this table (meas_period). The ones that will be stored in the database are described in Table 4.2.

Table 4.1: Parameters of the fingerprint table

Week	Format: YYWww (the capital W appears as a character)
Date	Format: YYMMDD
Time	Format: hhmmss
ΔT (s)	Rising time or drop time
P_L_i (W)	Total active power in phase i
Q_L_i(VAr)	Total reactive power in phase i
dP_L_i (W)	Difference between after-event and before-event active power values
dQ_L_i(VAr)	Difference between after-event and before-event reactive power values
U_L_i (V)	Phase voltage, RMS voltage

Table 4.2: Parameters of the measurements table

Week	Format: YYWww (the capital W appears as a character)
Date	Format: YYMMDD
Time	Format: hhmmss
P (W)	Total active power
Q (VAr)	Total reactive power
f (Hz)	Electric power frequency

4.3.2 Algorithms

In this project, Python programming makes possible to apply the necessary algorithms to fulfill the desired objectives. The code is divided into different modules depending on the purpose of the functions.

The starting point of the program is to read the parameters from the tables. As the eQL meter is provided with a fixed IP address, Telnet protocol can be used to communicate between the meter and the PC via Ethernet.

The program is a never-ending loop that asks the meter for new events every five seconds. This frecuency is enough to constantly monitor the changes from the electrical equipment. In case new events are recorded, the program will process the data to store it in the Django database. As Django is written in Python, this task was easy to implement.

Before storing the recorded events in the database, a device recognition process is done. In order to identify which appliance caused the new event, the corresponding fingerprint (defined by δP and δQ) is compared with the library of signatures.

However, events are measured in Watts and VArs while the vertices of the signatures are coordinates given in pixels of the graph picture. As a result, a scale process is needed. This task will be conducted by a simple rule of three involving the maximun values defined in the axis of the graph and the real number of pixels of the JavaScript tool. As these values must be fixed, the program will filter events with higher δP and δQ than the maximun values defined. According to the realized measurements, these values are: $\delta P_{MAX} = 3000, \delta Q_{MAX} = 800$. In addition, the size of the picture has been defined as 1350x800.

Once vertices and events are equivalent, the Point in Polygon algorithm explained in the previous section is used. It consists of proving if the new point ($\delta P_{scaling}$ and $\delta Q_{scaling}$) belongs to any polygon stored in the database. If a match is done, an identification is made. Otherwise, if no match is achieved or if more than one appliance have been identifyed with the corresponding fingerprint, the event will be identified as UNKNOWN_EVENT.

In addition to the events, the program will ask the meter for new data in the measurements table in order to obtain the total active and reactive power consummed. After reading the meter's answer and saving if necessary the data in the database, a new cycle of the loop will start.

4.3.3 Database Administration

The database reports the new events and measurements to the User Interface. As mentioned, the database is managed with Django. This web framework provides HTML templates with some variables and tags to separate the presentation of the document from its data [30].

The relational database scheme used in this system is given by Figure 4.6. As seen, there are three different classes: Devices and Events, which are related between each other and Measurements, which is independent. As the arrows show, one device (and its respective status) might be related with various events. On the other hand, one event must be identified with one device (and its respective status). As said, identified events will be labeled as UNKNOWN_EVENT.

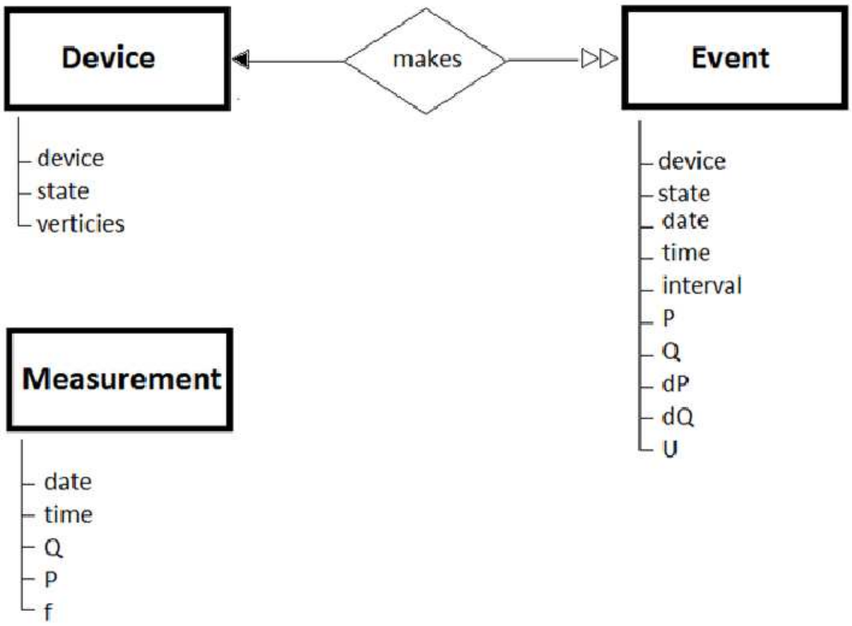

Figure 4.6: Relational database scheme of the Django administration

4.3.4 User Interface

The public interface must be simple and intuitive for the user. The monitoring system consists of a web application which has been developed in Django, HTML, and a Python plotting library called Matlabplotlib in order to represent graphs.

The website is divided into three entities:

- **Devices:**

  All the devices defined by the user are listed here. The user will be able to add or modify a device by defining its polygon signature in a two-dimensional graph. To do so, a JavaScript Line Drawing and Image Selection is used.

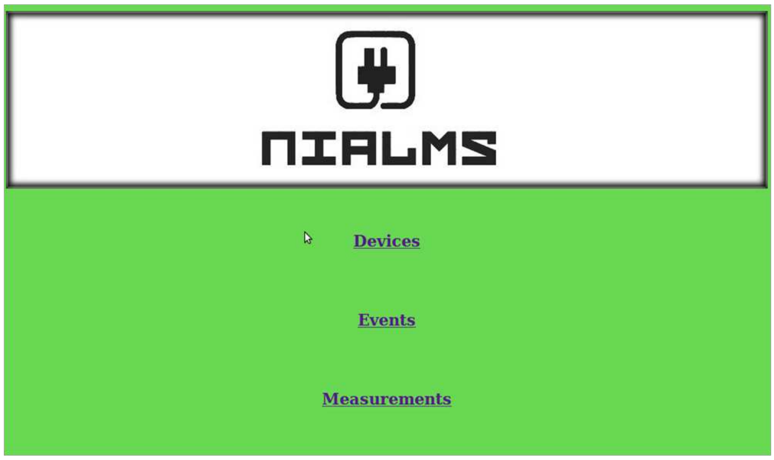

Figure 4.7: Index of the UI

The signatures will be stored in the database. If the user relates a new signature with the same device and status from an appliance stored in the database, the new definition will replace the old one. The main purpose is that users define more accurate signatures along the time in order to improve the precision of the system.

- **Events:**

  A list with the latest events is shown here. The list shows the identificated appliances (if possible) and the date and time of the different events. By clicking a chosen event it is possible to see the values of the parameters explained in Table 4.1. Besides, a two dimensional graph (δP versus δQ) is used to represent the events.

- **Measurements:**

  The user will be able to see a list with the latest measurements given by the meas_period table. The aim of this is to analyze the total power consumption as well as help in the identification of unusual load behaviour. In addition, latest measurements in total active and reactive power will be represented in order to offer the information in a more graphical environment (Figure 4.8).

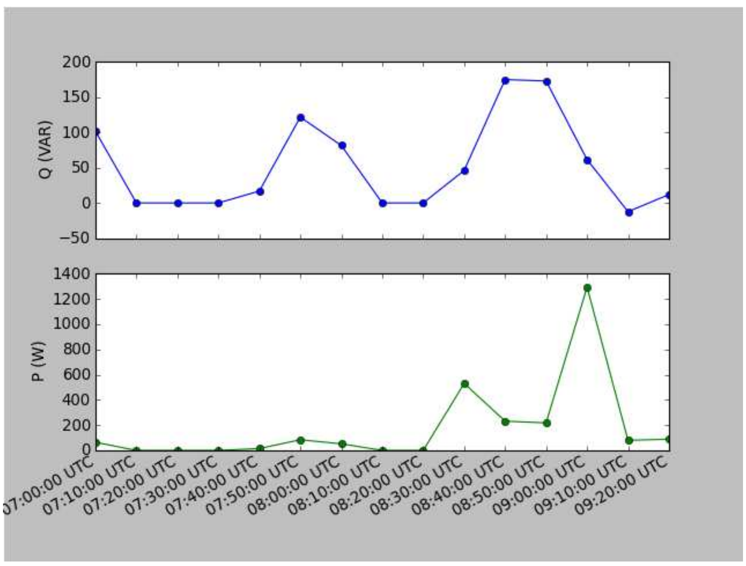

Figure 4.8: Example of the measurements graph in the UI

4.4 Manual System

The workflow system is given by the Figure 4.9.

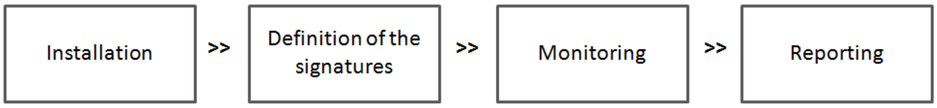

Figure 4.9: Workflow system

The first step corresponds to the meter installation which is the basis of NIALM systems. Figure 4.10 represents the installation of the meter, where each load can contain multiple devices connected. As appliances are wired in parallel, we can say that power consumption is additive.

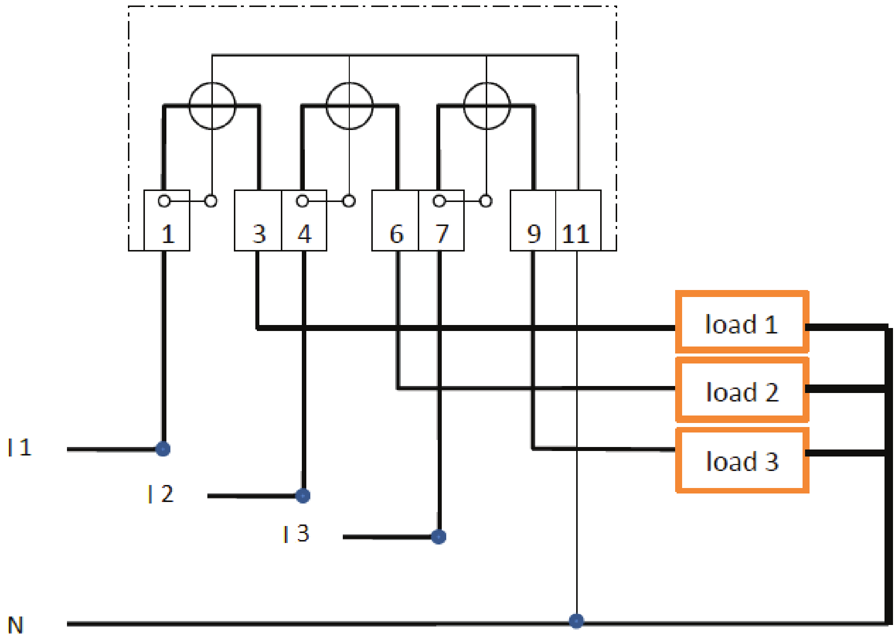

Figure 4.10: Meter installation

The eQL meter is able to measure the load consumption for each of the three electrical phases. The meter's inputs can be also connected to only one or two phases. For example in the experiment, all the electrical mains belong to the same phase.

As mentioned, measurements are stored in tables which are accessible by simple commands. These commands consist of the table's name (fp_table or meas_period) followed by a pound sign (#) and an argument which selects the information required. The argument "all" will show all the information on the table. However, as tables might be quite large it can be useful to select an interval defined by a starting time and an ending time with the format YYMMDD hhmmss (e.g. *fp#110522 000000-110522 090000* will search for events between 22-05-2011 at 00:00:00 and 22-05-2011 at 09:00:00).

After the meter's installation, a manually set-up has to be done in order to achieve the appliances' identification. This manual set-up consists of the definition of the signatures which is just drawing polygon verticies that surround the boundaries of the appliances' clusters. As this task will be done by the user, the public interface includes a tool to add or modify devices.

Once the polygon verticies are defined, the user must fill the form and press the submit button to complete the process. Figure 4.11 shows how this form looks like.

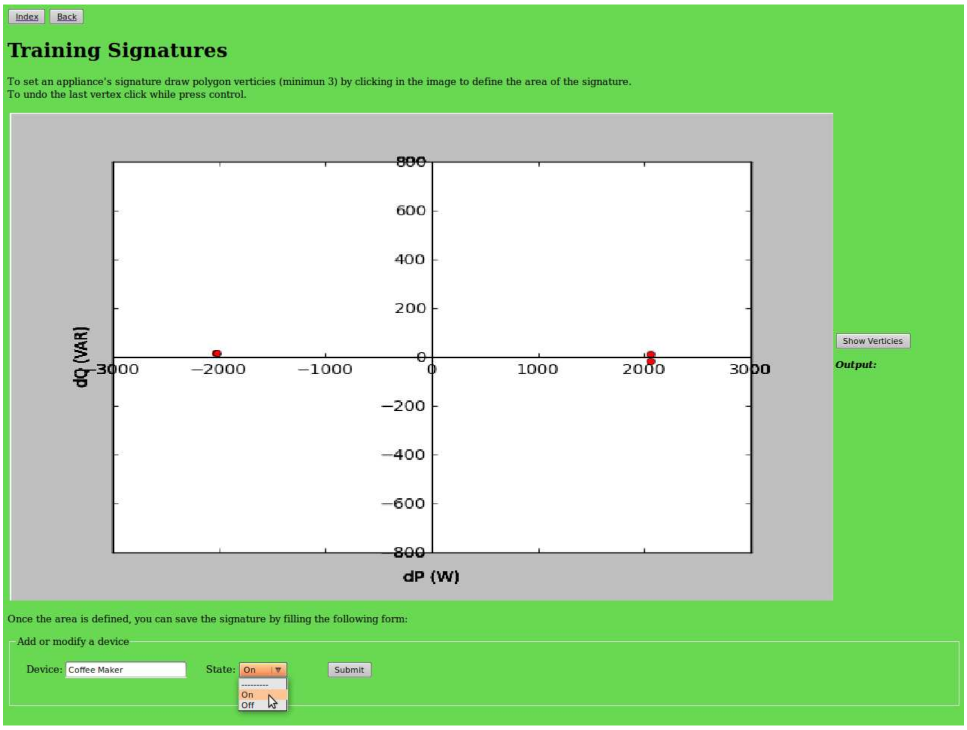

Figure 4.11: Form and JavaScript tool to define new signatures in the UI

Finally, when the meter's installation and the definition of the signatures are completed, it is possible to start monitoring the events of the electrical equipment by measuring the power consumption. This measurements will be reported to the public interface with the purpose of informing about the appliances status to the user and people concerned.

5

Tests and Results

5.1 Basic Test

As said in Chapter 1.3, this test was performed on table top in an office to prove and develop the system by using only two appliances: a coffee maker and a lamp.

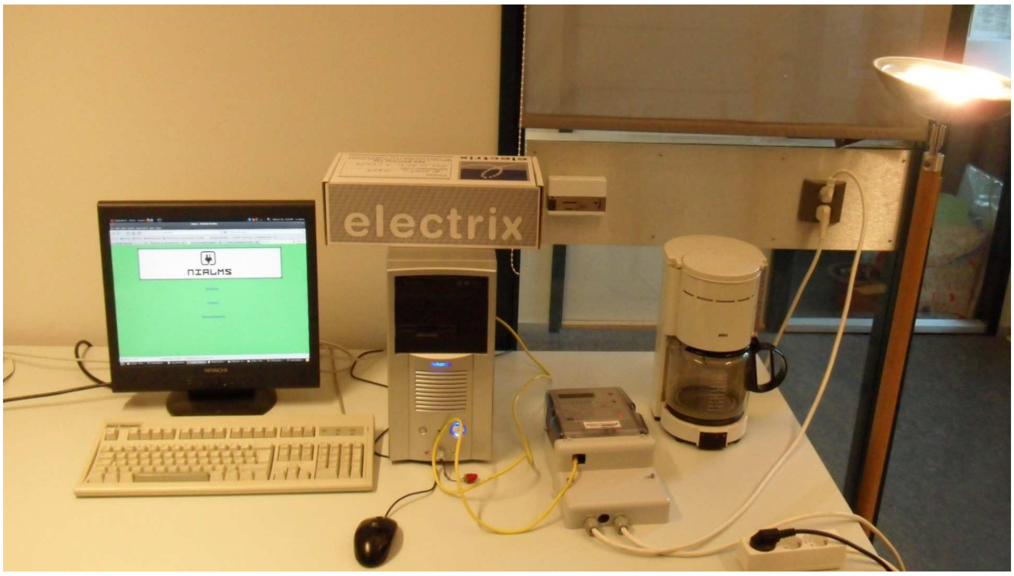

Figure 5.1: Set-up of the basic test

5.1.1 Appliance Signatures

Signatures in this section do not correspond to the vertices of the clusters area but to their mean power values. On the other hand, as a result of the meter's tolerance and some other factors (e.g. device's temperature), events rarely match with the exact signature. Nevertheless, it is possible to consider the signature as the average of a high number of measurements where events form clusters around.

Table 5.1 lists the on-signatures of both devices. Off-signatures have been omitted as they are almost symmetrical to on-signatures.

Table 5.1: Device's signatures for basic test

Appliance	dP/W	dQ/VAr
Lamp	200	0
Coffee Maker	1000	0

As shown, both the lamp and the coffee maker do not consume reactive power which means that they are resistive. However, in practice electrical loads connected to AC power can consume both real and reactive power. Therefore purely resistive behaviour is not always possible. The result is that fingerprints might present low reactive power because the power factor value is sometimes below 1.

The resistive behaviour of the appliances considered in this test can be confirmed by understanding the performance and the main elements of each:

- **Lamp**

  A halogen lamp is used in this test. This light source is an incandescent lamp with a tungsten filament contained within inert gas and a small amount of halogen. The filament is a very thin threadlike wire that offers resistance to the passage of electric current.

- **Coffee Maker**

  This appliance brews coffee based on heat transfer. When turned on an electric current begins to flow through a resistance, heating up the water in the chamber. Once the boiling point is reached, the water will boil into the funnel. After that, coffee will keep warm by some heating cycles consisting in many on and off events of variable duration controlled thermostatically.

5.1.2 Test Protocol

After having measured these appliances individually, it is time to measure the combination of both in order to prove that it is possible to distinguish between the lamp and the coffee maker by the method proposed. With that purpose the protocol in Table 5.2 has been tested. This table shows different actions carried out in both appliances and their corresponding events reported by the meter.

Notice that not all the events given by the meter correspond to an action from the test protocol. This can be explained by the warming cycles of the coffee maker. As said those events are not controlled manually but thermostatically. The reason why automatic on-events are not seen in the table is that the test was no long enough to cool the thermostat and cause a new on-event.

On the other hand, this coffee machine uses the same resistor for brewing and warming up coffee. As a consecuence of this fact, it is not possible to assert when a person is making coffee or when the machine is just warming it. Activity monitoring is therefore uncertain in this case, because the meter will register events periodically which will not correspond to any human activity.

The results of the previous test protocol are represented in Figure 5.2. These results as well as those of analogous tests, reveal that it is possible to distinguish both appliances by the method proposed with a 100% accuracy. The reason of this is that appliance signatures are perfectly defined in small clusters far from each other, which makes impossible that they overlap. This is due to the low number of devices and their different power consumption.

Table 5.2: Test protocol for basic test

Actions		Events		
Device	**Status**	**dP/W**	**dQ/Var**	**Time**
Coffee maker	ON	1009	-10	00:00:00
-	-	-973	14	00:00:22
Lamp	ON	202	0	00:00:43
Coffee maker	Pouring water	1006	8	00:02:46
Lamp	OFF	-205	-3	00:02:51
-	-	-976	0	00:04:19
Lamp	ON	207	-3	00:07:06
-	-	1002	-6	00:07:28
Cofee maker	OFF	-995	0	00:07:30
Coffee maker	ON	1007	13	00:09:21
Coffee maker	OFF	-972	-11	00:10:35
Lamp	OFF	-206	0	0 0:11:09
Lamp	ON	200	0	00:11:20

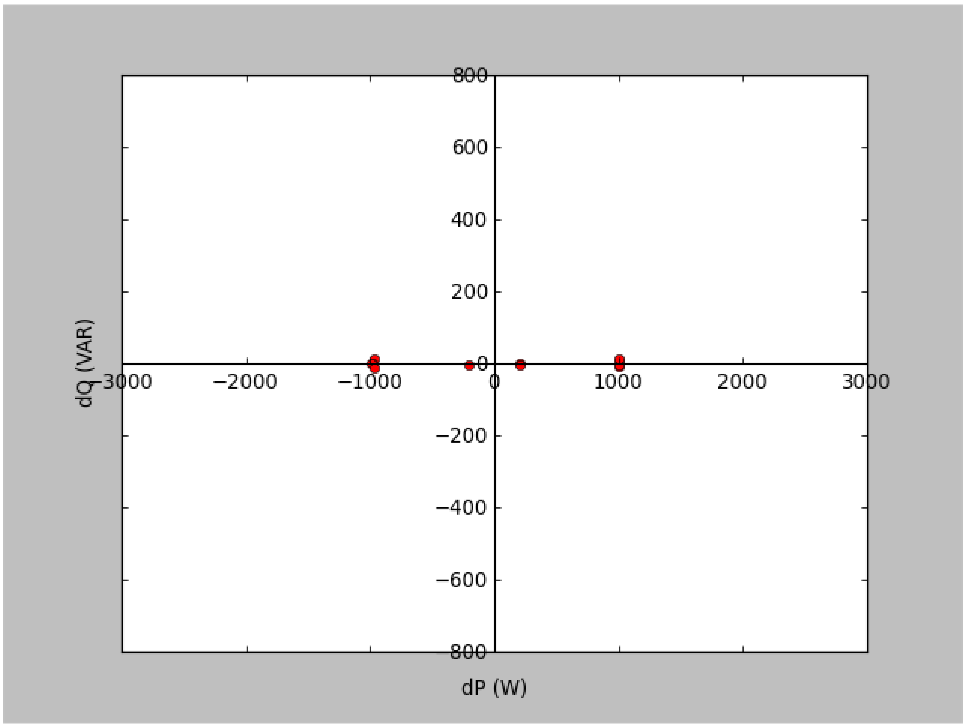

Figure 5.2: Two-dimensional representation of the basic test protocol

5.2 Lab Test

This test was much more challenging than the previous one as it involves more devices. In the lab test, all devices found in the department's kitchen were analyzed. Nevertheless, only some of them were valid for the purpose of this work.

5.2.1 Appliance Signatures

Two-state Appliances

The on-signatures of this group of appliances is presented in Table 5.3 and Figure 5.3:

Table 5.3: Two-state device's signatures for lab test

Appliance	dP/W	dQ/VAr
Coffee Maker	2080	0
Water boiler	2280	0
Refrigerator 1	890	460
Refrigerator 3	70	160
TV	0	0
Computer speakers	-	-
Fishbowl lamp	-	-
Fishbowl water filter	-	-

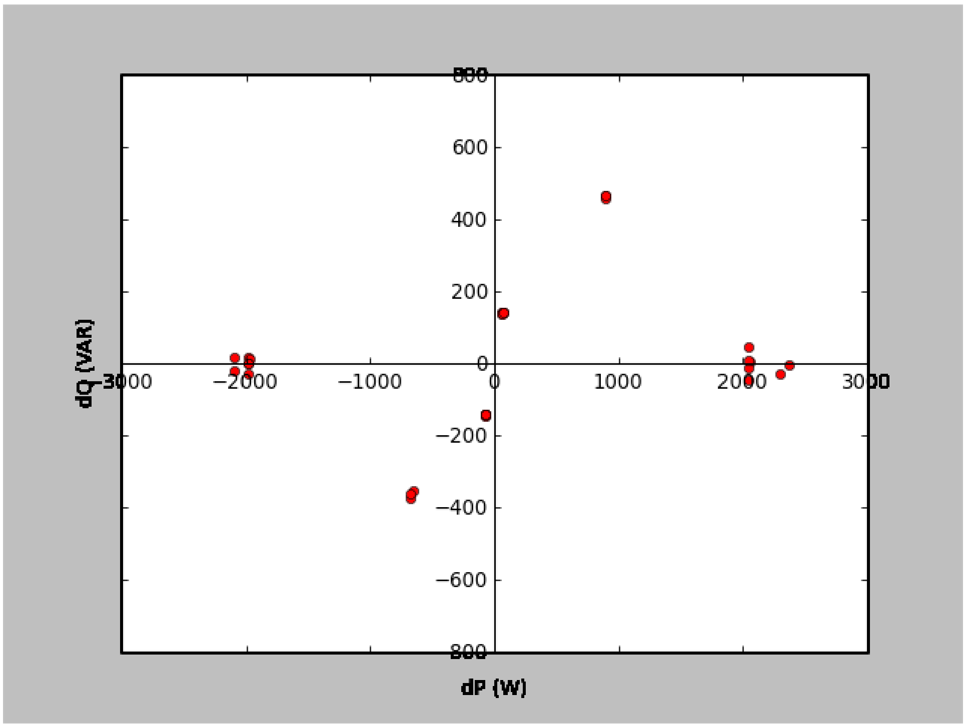

Figure 5.3: Fingerprints of the coffee maker, water boiler and refrigerators

Devices with low power consumption such as speakers which consume less than 7 watts, could not be defined with a signature. The reason is that the power meter used in this work can only record loads bigger than 50 watts in active power or 20 VArs in reactive power. However, those devices are not related to any kitchen activiy, so they are not going to be considered in the analysis anyway.

The TV is a plasma screen and it presents an unusual signature. It can be included in the group of low power consumption devices. As a consecuence, the meter is not able to record events coming from this appliance. On the contrary, this is not what always happens. From time to time the meter records on-events of $dP = 0$ W and $dQ = 0$ VAr. In addition, off-events only appear when switching off the device after it has been on for a while. Its off signature is $dP =$ -130 W and $dQ = 45$ VAr.

This behaviour can be explained by the operation system of the TV. The power consumption of the a plasma screen can vary greatly depending on what it is being watching. Bright scenes require more energy than dark scenes. For that reason and because of the quickly variation of images, on and off signatures differ from each other.

Fridges usually have different cooling programs. Therefore it is possible to think that they belong to the multi-state appliances group. However, there are three refigerators in the kitchen and two of them present a two-state signature. This means that every program consumes the same power in larger or shorter periods of time.

As in the basic test, the rest of the elements from the list are purely resistive. However, this time will be harder to distinguish between them because the signatures from the water boiler and the coffee maker are close in the real power axis.

To better understand the electrical behaviour of these appliances, it is necessary to take a look at the operation system of each of them:

- **Coffee Maker**

  This coffee machine has a different behaviour from the one used in the basic test. It has three different resistors: one to heat the water until it boils, and two others to warm up the coffee after is done. As both groups of resistors have different value, it is now possible to recognize when the coffee maker is brewing or warming up coffee.

  In fact, this is a multi-state appliance. Nevertheless, as this project is focused in people's activities (e.q. making coffee), the signature of this device will correspond to the brewing process.

- **Water Boiler**

  Electric water boilers are similar to coffee machines. Both devices, are two of the most consuming appliances in the department's kitchen.

  This appliance consists of a water deposit with a heating element which converts electrical energy into heat. This is possible by the principle of Joule heating: electric current through a resistor converts electrical energy into heat.

  This appliance will be automatically shut off when an internal thermometer detects that water has reached its boiling point. Although the signature of this water boiler is close to the coffee maker's one, both appliances can be identified almost every time.

- **Refrigerators**

  The Refrigerator is the major need of todays kitchens. It is also one of the major power consumers as it is used day and night.

  This appliance comprises a thermally insulated compartment and a heat pump to transfer heat from it to the external environment. Refrigerators have on and off cycles controlled by a thermostat, also refered to as cooling cycles.

  As this device is not controlled manually, it will not correspond to any kitchen activity. However, it is possible to identify some other activities by analizyng its cycles' frequency, for example if new food has been placed into it or if the door has been opened.

Multi-state Appliances

- **Kitchen Stove**

  The kitchen stove uses resistive heating coils which heat iron or ceramic hot plates. This particular stove has two plates of different size. Each of them have six cooking programs meaning that different currents will flow through the resistors. Thus, the signatures of both plates are resistive. Besides, the state model of this appliance is complex but the signatures have been measured with respect to the resting state (off).

Looking at the signatures presented in Table 5.4 and Figure 5.4 it is possible to say that kitchen stove's fingerprints appear along the resistive axis. Therefore, kitchen stove represents a very complicated multi-state appliance as its resistive signatures overlap with the ones of many other appliances.

In addition, the signatures vary with the temperature of the plates. This makes device recognition difficult and thus, hard activity identification. Notice that sometimes it is easy to confuse between both hot plates because signatures are close. However, as this work is focused in people's activities it is not important to differenciate between both plates to determine that the person is cooking.

Table 5.4: Signature of the kitchen stove

Plate	**Program**	**dP/W**	**dQ/VAr**
Small plate	P1	145	0
	P2	180	0
	P3	260	0
	P4	530	0
	P5	750	0
	P6	1550	0
Big plate	P1	200	0
	P2	250	0
	P3	320	0
	P4	900	0
	P5	1225	0
	P6	2150	0

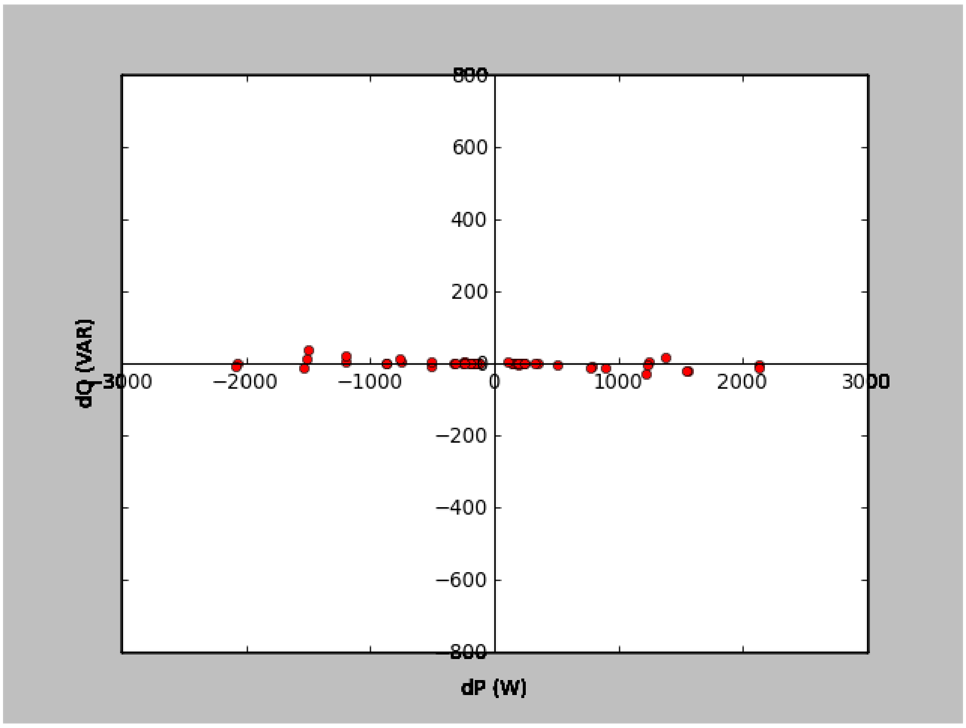

Figure 5.4: Kitchen stove's fingerprints

- **Microwave oven**

  This appliance consists of a cavity magnetron which converts high-voltage electric energy to microwave radiation. Its high voltage capacitor connected to the magnetron, makes the load to be a reactance and resistance combination.

  For every microwave program, one short period operation includes many on and off events. In the case of this specific microwave oven, these events appear in five different regions of the $\delta P, \delta Q$ plane as Figure 5.5 shows.

  From the figure, it is possible to see that there two clusters with a noticeable higher amount of events. These clusters will be used for the appliance's identification while the more occasional clusters will be ignored.

  Notice that some microwave ovens have also Grill mode. This special program uses the Joule's principle to heat a resistor as in the ordinary heating devices (Table 5.5).

Table 5.5: Signature of the microwave oven

Program	dP/W	dQ/VAr
Microwave	1300	350
Grill	1150	30

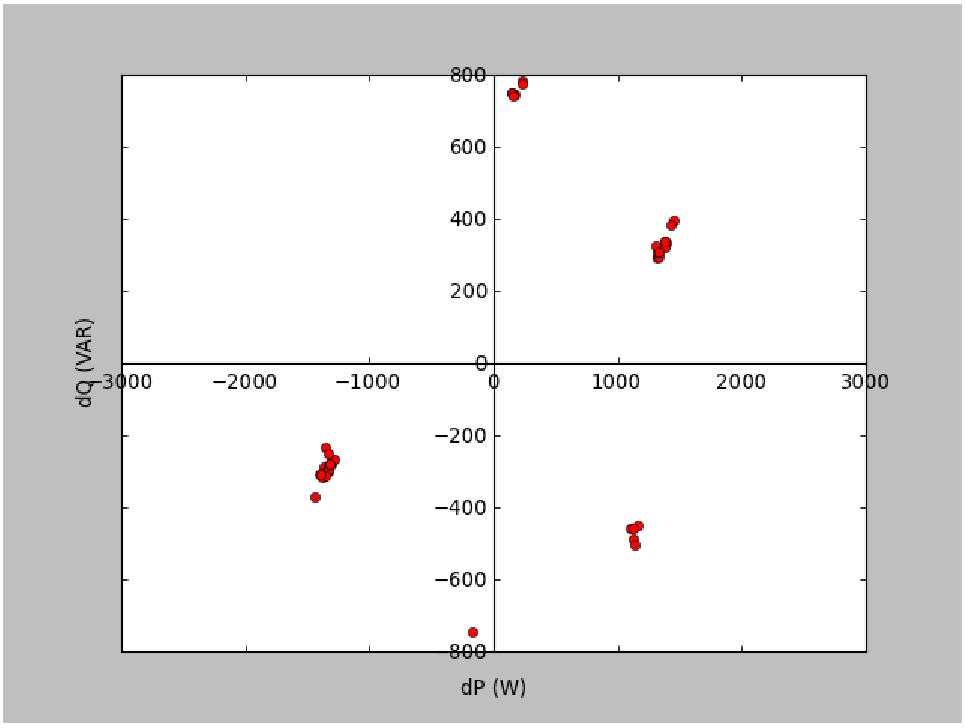

Figure 5.5: Microwave's fingerprints

- **Refrigerator with Freezer**

  Unlike the rest of the refrigerators in the kitchen, this one contains a freezer compartment which mantains the temperature below 0 °C. This means that the machine has two different thermostats to control both temperatures.

  As a result, this appliance has three power states although the operation system of the device is the same than the rest of the fridges in the kitchen (see Table 5.6 and Figure 5.6).

Table 5.6: Signature of the refrigerator 2

dP/W	dQ/VAr
1050	375
-820	-240
-75	-116

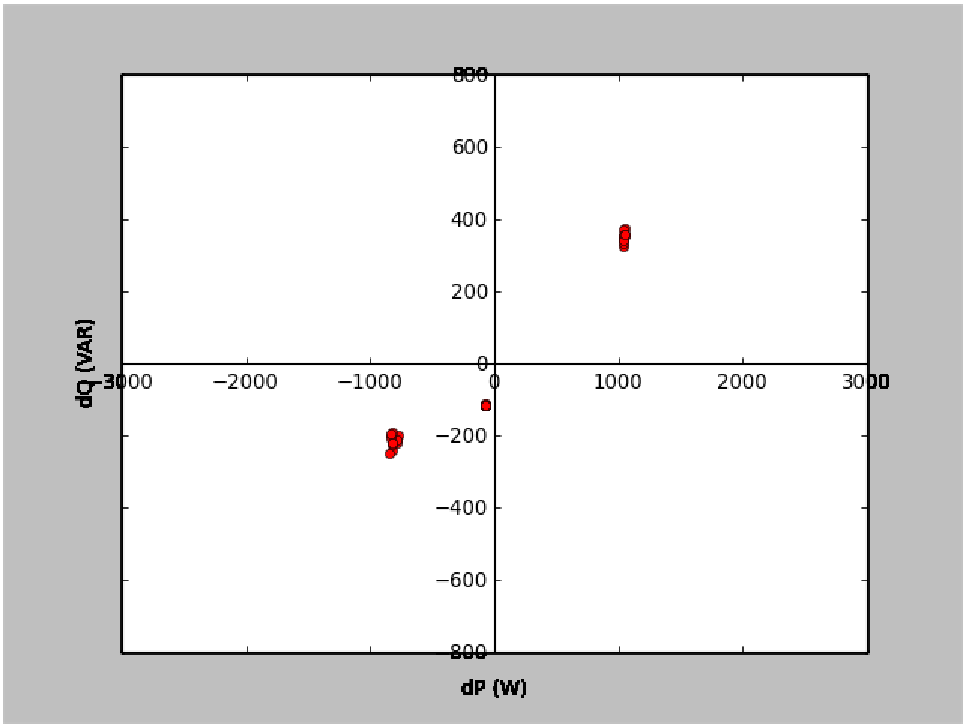

Figure 5.6: Fingerprints of the refrigerator 2

- **Dishwasher**

  Dishwashers normally have a thermostatically controlled heating resistor and a motor for pumping water. As everyone knows, theses appliances have different washing programs but all of them present the same fingerprints. The reason is that the resistor and the pump use the same energy to work in every program, but in different periods of time.

Table 5.7: Signature of the dishwasher

Action	dP/W	dQ/VAr
Heating water	2060	50
Pumping water	75	80

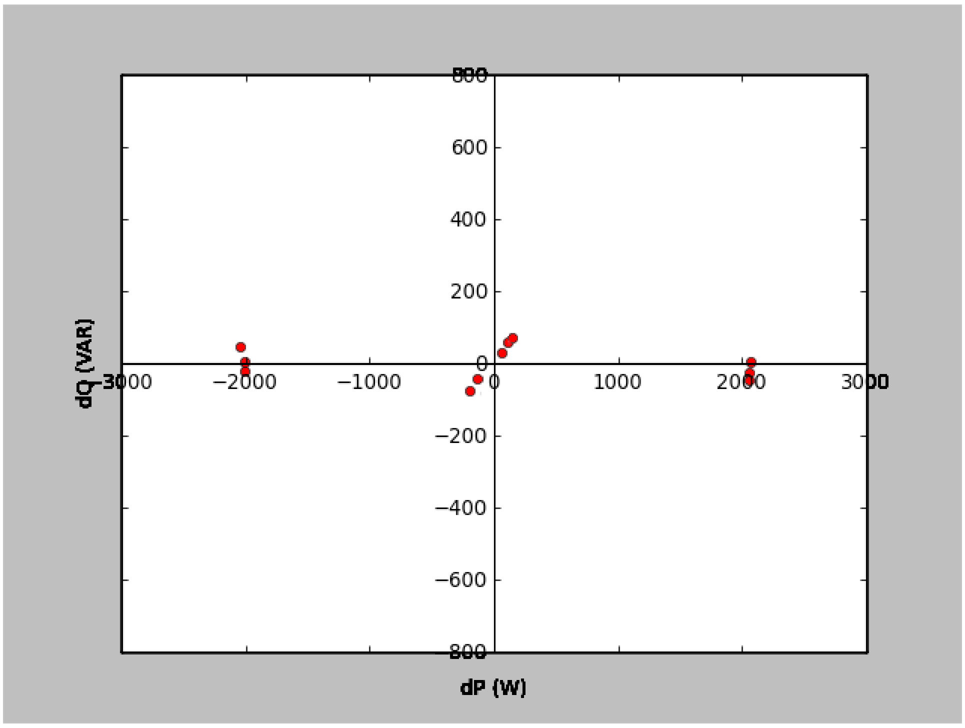

Figure 5.7: Dishwasher's fingerprints

5.2.2 Test Protocol

As in the basic test, a test protocol was performed to test the accuracy of the system in a more realistic environment. However, as seen in the previous section some devices were excluded from the analysis.

The kitchen activities proposed for this test are listed in Table 5.8. As in the basic test, the right side of the table correspond to the actions performed while the left side corresponds to the resulting events.

Once again, not all the events given from the meter correspond to an action from the test protocol. The reason of this is that some appliances are not controlled manually but thermostatically. For example, the water boiler and coffee machine switch off authomatically while the washer machine and the microwave oven work by cycles. In addition, refrigerators were on during the test causing fingerprints at the same time.

Figure 5.8 represents the fingerprints obtained in this test. Although the number of samples for each appliance is low, it can be said that the accuracy of the system is below 100%. This is caused by overlaping fingerprints such as the resistor from the dishwasher match with the signatures of the coffee maker and the water boiler.

The exact accuracy of the implemented prototype is not shown as it depends on different factors such as the amount and type of devices or the definition of the signatures. However, the basic test shows that it is possible to get the 100% accuracy if devices have clear signatures definitions which do not overlap.

Table 5.8: Test protocol for lab test

Action		**Event**		
Device	**Status**	**dP/W**	**dQ/Var**	**Time**
Water boiler	ON	2049	-9	00:00:00
-	-	-1978	-15	00:01:08
Coffee maker	ON	2165	44	00:02:36
-	-	-2105	29	00:05:51
Kitchen stove	ON (small plate - prog 3)	245	2	00:09:00
Microwave	ON (850 W)	1440	365	00:10:02
Microwave	OFF	-1436	-347	00:11:02
Kitchen stove	OFF	-257	0	00:11:29
TV	ON	-	-	00:11:50
TV	OFF	-102	36	00:13:02
Water boiler	ON	2044	-13	00:14:06
-	-	-1980	-32	00:14:35
Coffee maker	ON	2158	-27	00:15:31
Kitchen stove	ON (small plate - prog 3)	254	-4	00:16:00
Microwave	ON (850 W)	222	710	00:18:30
-	-	-932	-3550	00:18:32
-	-	78	115	00:18:59
Microwave	OFF	-1377	-316	00:19:21
TV	ON	-	-	00:19:30
TV	OFF	-133	31	00:20:12
Dishwasher	ON	2064	0	00:40:47
-	-	1050	354	00:43:10
-	-	-838	-216	00:43:12
Kitchen stove	OFF	-253	0	00:53:38
-	-	-2040	30	00:55:14
-	-	-72	-137	00:56:35
-	-	2059	-8	00:56:52
-	-	-74	-112	01:00:38
-	-	-2034	21	01:05:47

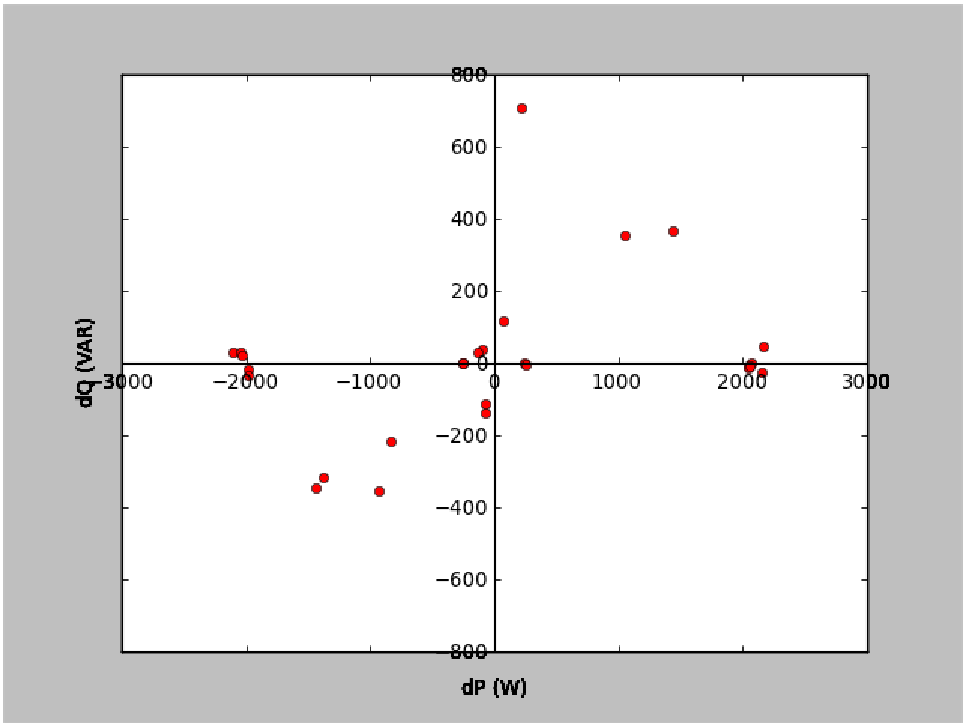

Figure 5.8: Two-dimensional representation of the lab test protocol

6

Conclusions and Future Work

6.1 Summary of Work

In this Final Project, a Non-Intrusive Appliance Load Monitoring System prototype has been implemented with the purpose of monitoring people's activities inside the kitchen environment.

NIALMS is based on a single power meter which constantly measures the total power consumption. As Figure 6.1 shows, electrical appliances events make both positive and negative changes in the electric load demand. Because each device has a different power consumption, it is possible to recognize the profile of each (appliance signature).

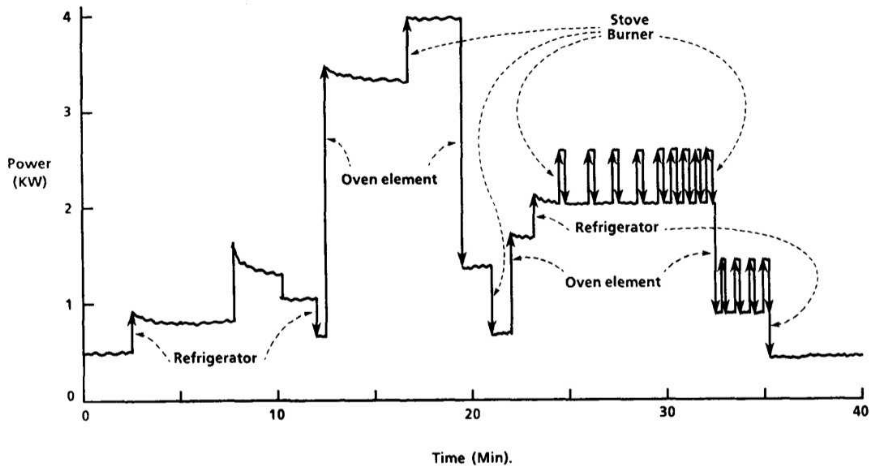

Figure 6.1: Total load shows step changes due to individual appliance events [5]

The implementation proposed in this work is mainly divided into two: the recording and the monitoring systems. The recording system consisting of the power meter, is responsible for performing the electrical measurements as well as detecting the events. On the other hand, the monitoring system in turn consists of two parts: load identification algorithms, which relate an event with the device; and the public interface, which is responsible for displaying the events's history to the user via HTTP protocol.

The state of art of NIALMS proposes different methods for the load identification algorithms implementation. In this work a cluster analysis have been chosen, which consists of a two-dimensional graphical interpretation of steady-state signatures. The main idea is to make a database with the signatures of the devices. Thereafter, the load identification algorithms will be able to recognize the device which caused the event by comparing it with the signatures library.

After the development of the system, electrical data was collected for each appliance in order to build up the database. Besides, the identification process was tested measuring combination of several appliances. Finally, the system was implemented in a higher level platform called ThereGate.

6.2 Conclusions

NIALMS can estimate the number and nature of the individual loads, their energy consumption, and time-day variables. For that reason, it is possible to use it for monitoring people's activities. Although it was demonstrated that daily behaviour could be monitored with this procedure, experiments were not realized in a home environment so daily behaviours are not realistic.

The results of this study reveal that it is possible to achieve the goals set by a simple graphical analysis. However, the larger number of devices the greater the difficulty of identification is. In fact, exact NIALMS accuracy is very difficult to quantify. The precision of the developed system depends on the amount and type of devices used and the precision with which the signatures are defined.

As seen in Chapter 5.2, the events of the electrical equipment are mostly distributed along the real axis between 50 W and 2400 W. This means that most kitchen appliances are resistive and therefore, some signatures overlap (e.g. kitchen stove with every resistive appliance).

Therefore, the system requires a deeper study in the signatures of the devices. The algorithm clearly works well, but can be improved by adding a third parameter to the definition of signatures. In that case, the system accuracy would increase dramatically. This is what is done in advanced monitoring systems through a Fourier analysis of current for synthesizing harmonics of the variation in time.

As a curiosity from the results, although the newer fridges (refrigerators 1 and 3) seem to consume more power, the older one (refrigerator 2) has a higher number of cycles in the same interval of time.

6.2.1 NIALMS Advantages and Disadvantages

Unlike ordinary monitoring systems which utilize multiple sensors or meters, NIALMS collects electrical data by sampling the power consumption at a single point. This means fewer components to install, mantain, and remove [5].

Besides, remote monitoring makes possible to access the data anytime and anywhere through Internet. This represents a great advantage because of a reduction in cost and simplified installation. What's more, NIALMS cost and complexity are independent of the number of monitored appliances [5].

Intrusive methods require a certain degree of equipment to do the installation and stored the data. Therefore, they are not the same attractive solution than non-intrusive systems. However, in situations where non-intrussive techniques do not provide enough information, intrusive techniques are necessary. This means that NIALMS also presents some cons.

First of all, NIALM systems invlolve simple hardware but complex software due to the signal processing and analysis. In addition, a manual set-up is needed in order to name the devices and define the signatures.

Secondly, the system is not able to detect every device. As seen in the lab test (Chapter 5.2), the noise from the recording equipment makes it impossible to identify low power consumption appliances. Besides, appliances that are permanently on (e.g. telephones) are also invisible to the event recorder because the signatures are missing. Continuously variable power consumption devices (e.g. sewing machines) cannot be detected either. The reason is that they have an infinite number of states with a truly continuous range of operating power levels, and so they do not generate consistent step-chage signatures. This is not a significant limitation for residential load monitoring purposes because of the insignificant amount of energy consumed by this class of appliance. It is likely to be more important in commercial and industrial applications, where variable-speed drives are more prevalent [5]. Exclusive systems and algorithms must be designed and developed to their detection.

Table 6.1: Classification of various household appliances

Appliances	**Examples**
Permanently On	stand-by loads, telephones, clocks, aquarium pumps, etc.
On-Off	PC-monitor, electric lighting, kettle, toaster, etc.
Finite State Machines (FSM)	washing machine, dishwasher, PC-printer, microwave, etc.
Continuously variable	HIFI- units, lighting with dimmer, sewing machines, variable-speed drills, etc.

Another problem is NIALMS errors due to big fingerprint clusters. Small-sized clusters result from very consistent appliances, especially resistive heaters. Thus, they are easier to recognize. However, electrically identical appliances cannot be distinguished.

Besides the mentioned disadvantages, NIALMS has privacy concerns as it provides private information. For example, it is possible to know whether a person is at home or not, and even more where exactly in the house that person is and what he or she is doing. As a solution, in order to protect the privacy of the people, a security system must be implemented.

6.3 Future Development

Medical professionals are increasingly interested in monitoring systems in people's homes because these activities can help maintain and improve living conditions. Although this project has been focused on the kitchen environment, the activity monitoring system could be used in other areas such as toilets or living rooms. However, it might be inappropriate for large spaces due to the increased probability of simultaneous events.

In order to improve the system and deal with the drawbacks mentioned above, a future development of the proposed NIALM system should be made:

- Most of the devices in the kitchen are resistive. Thus, the probability of having overlaping signatures is high. This situation could be avoided by inserting known reactance in the loads. In other words, it is possible to change the signatures of the devices by including capacitive load in the appliances in order to improve the appliance identification. However, this would require physically modifying the devices.

- In addition, it would be possible to manage the appliances remotely by the monitoring application. That is, the user will be able to switch off appliances by inserting fuses in the devices. Nevertheless, it would require a more elaborated installation of the system.
- On the other hand, although the user interface is concern for access to seniors and people with disabilities, it could have followed the standards of web accessibility for people with disabilities.
- The improvement of the system involves also the event recorder. Research in load disaggregation should be done in order to find better events identification, especially with low power consumption appliances and simultaneous events.
- An automatic set-up and a privacy control should be also developed. In addition, an algorithm to hide the cycles of the devices in a way that, only the events which correspond to a human activity are shown to the user.
- Future development of the system can also involve the analysis of the cycles from the electrical equipment because it is possible to reveal device failures by analyzing unusual power consumption or changes in cycle characteristics.

The expectations of NIALMS are very high in different applications (Chapter 4.4.2) due to its low price and simple installation. Load monitoring can be useful for users, regulators, utilities, appliance manufacturers, and other stakeholders[32]. The most important expectations nowadays involve Smart Grid applications. Knowing how and when electricity is used permits to advance and charge in a smarter way.

Nevertheless, there are more applications were NIALM systems may be extremely valuable but that have not been yet explored. For example, situations without physical access to individual loads such as submarine or extraterrestrial locations [5].

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Glossary

Activities of Daily Living Routine activities that people tend do everyday such as eating, bathing, or dressing.

Aging in Place Term used to describe the provision of care necessary to allow a person live independently rather than institutionalized.

Appliance Signatures Electrical measurable parameters that give information about the nature and operating status of an appliance.

Asistive Automation Providing aid or assistance by using different technologies.

Assisted Living Maximizing a person's independence and dignity by providing services and health care support.

Assisted Living Facilities Facilities that help with everyday tasks to ensure health, safety, and well-being.

Cluster Analysis Studying the different clusters or groups formed by the appliances events in a graphical interpretation.

Event A step change in power due to the change of an appliance's operating state to another.

Home Automation Providing aid or assistance in the patient's home by using different technologies.

Instrumental Activities of Daily Living Tasks that enable a person to live independently in a community such as cooking or driving.

Interoperability The ability of devices to replace or work with other devices from different manufacturers without modification.

Kitchen Activities Human activities performed in the kitchen environment and related to an appliance.

Load Anything that uses electricity. They can be divided into resistive, inductive or capacitive.

Monitoring Supervising activities for the purpose of regulation or control.

NIALMS Analyzing electrical changes to deduce what appliances are used as well as their individual energy consumption.

Non-intrusive Systems They do not require to intrude into an appliance to collect data about it.

Remote monitoring Monitoring performed away from the place at which the monitored activity is occurring.

Smart Grid Electrical grid which attempts to predict and respond to the behaviour and actions of all electric power users connected to it.

Smart Power Meter New generation of meters with additional features for easy and efficient monitoring of power consumption.

Steady-state A stable condition that does not change over time or in which change in one direction is continually balanced by change in another.

Technology Driver Software that allows a specific technology to interact with a hardware device.

Telnet Protocol Network protocol used to access via a network to another machine for remote management.

ZigBee Specification for a suite of high level communication protocols using low-power digital radios based on an IEEE 802 standard.

Z-Wave Proprietary wireless communications protocol designed for home automation, specifically to remote control applications.

A

The System

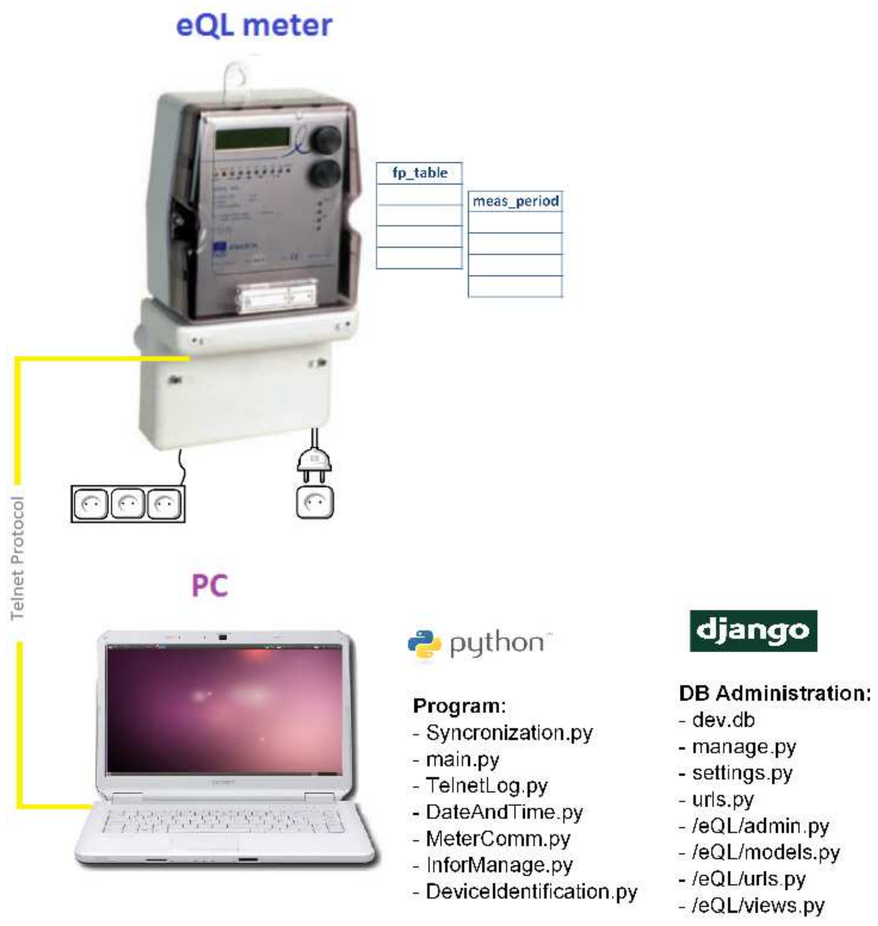

Figure A.1: The system

A.1 Database Administration

The database administration was developed with Django supporting sqlite3 by following the official documentation (`http://docs.djangoproject.com/en/1.2/`).

A.2 Program

The Python code was organized into different files according to the aim of the functions. There are two independents programs: *Synchronization.py* in order to synchronize the meter with the PC, and the *main.py* which is responsible of the appliances identification.

A.3 User Interface

The development of the public interface was done in HTML. In addition, a GUI supported by Django called Matlabplotlib was used in order to make the graphs (`http://matplotlib.sourceforge.net/`).

The definition of the signatures was possible by using a JavaScript Line Drawing and Image Region Selection tool developed by Britton Leo Kerin (`http://www.brittonkerin.com/image_region_selector/irs_demo.html`).

B

The Meaning of Load

This apendix is based on the slides developed by INELAP company (`http://www.conae.gob.mx/work/sites/CONAE/resources/LocalContent/2155/1/images/Comp_pot_reactiva.pdf`) in order to explain the basic concepts related with electric loads and powers.

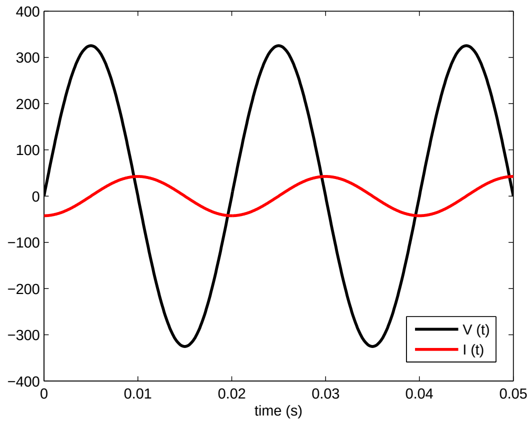

Figure B.1: Voltage and current waveforms

Most of the European countries, such as Finland or Spain, use an AC mains supply of 230 V at 50 Hz for home electricity. However, this voltage do not determine the peak voltage but its root mean square value (RMS value) which is the time-averaged power delivered equivalent to a DC voltage of 230 V.

$$V_{rms} = \frac{V_{peak}}{\sqrt{2}} \tag{B.1}$$

In an Alternating Current circuit, including household power, both current and voltage are sinusoidal. As Figure B.1 shows, this means that they vary depending on time.

Voltage, also called electric tension, measures the energy per unit charge. It is always measured between two points and it can represent a source or a lost of energy. Its unit in the metric system is the volt (V).

$$V_{AC} = V_{peak} sin(\varphi) \tag{B.2}$$

Electric current is a flow of electric charge usually carried by moving electrons in a conductor material. The SI unit for measuring it is the ampere (A). Unlike the electric tension which can exist in absence of current, this one will only appear when the circuit is complete.

$$I_{AC} = I_{peak} sin(\theta) \tag{B.3}$$

B.1 Loads in Electrical Systems

Anything that uses electricity (either AC or DC) is referred to as an electrical load. As a consecuence, standard household appliances are AC loads and like in every electric system, they can be divided into three different gorups:

- **Resistive:**

  Resistive loads can be found in devices such as irons, heaters, or incandescent lighting. Their main element is a resistor which presents opposition to current flow. As Figure B.2 shows, both voltage and current waves are in phase in this group of loads. This means that the phase vector or phasor is zero.

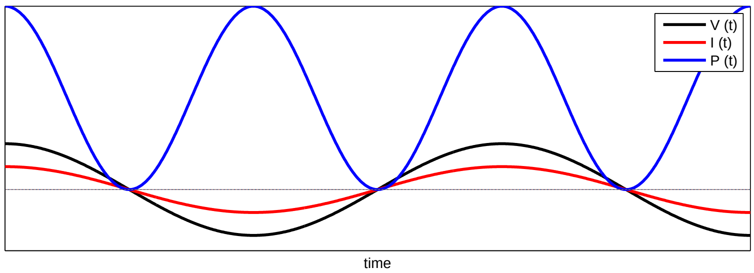

Figure B.2: Power, voltage and current waveforms in resistive loads

- **Inductive:**

  Transformers, induction motors, fluorescent lighting, and welding machines are some examples included in this group. They are also known as lagging loads because the alternating current lags behind the alternating voltage of the load. The phasor in this case is -90°.

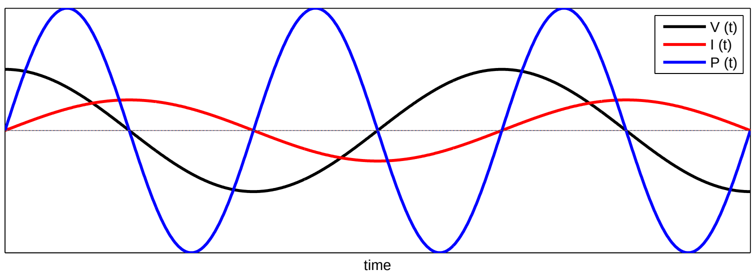

Figure B.3: Power, voltage and current waveforms in inductive loads

- **Capacitive:**

  Capacitive loads draw current that leads the voltage. Therefore, these loads are just the opposite than the previous ones. This group covers capacitor banks, synchronous motors, and synchronous condensers. Looking at Figure B.3 it is possible to appreaciate that the phasor is the same than the inductive one but with opposite sign.

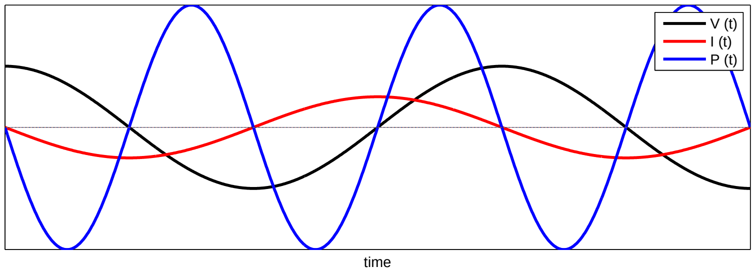

Figure B.4: Power, voltage and current waveforms in capacitive loads

As seen, loads are classified according to voltage and current waveforms. However, by definition, loads can also be differentiated according to the power waveform which is as well sinusoidal.

$$P_{AC} = V_{AC}I_{AC} = V_{peak}sin(\varphi)I_{peak}sin(\theta) = P_{peak}sin(\psi) \tag{B.4}$$

In resistive loads, the product of voltage and current is always possitive. This indicates that the instantaneous power is unidirectional meaning that it will always supply the load. The formula of the instantaneous power for this group of loads is given by:

$$P_R(t) = \frac{V_pI_p}{2} + \frac{V_pI_p}{2}cos(2wt) = V_{rms}I_{rms} + V_{rms}I_{rms}cos(2wt) \tag{B.5}$$

For purely reactive loads, the voltage and current are ±90 degrees out of phase. This means that now power is bidirectional indicating that it can flow from the source to the load and vice versa. As the formulas below show, the mean power value for this group of loads is null:

$$P_L(t) = \frac{V_pI_p}{2}sin(2wt) = V_{rms}I_{rms}sin(2wt) \tag{B.6}$$

$$P_C(t) = -\frac{V_pI_p}{2}sin(2wt) = -V_{rms}I_{rms}sin(2wt) \tag{B.7}$$

Figure B.5 shows the power waveforms for resistive, inductive and capacitive loads. However, in the practice loads are usually a combination of resistance, inductance and capacitance. For example, for a resistive-inductive load there is a current component in phase to the voltage and another component lagged 90°. The total current will be the phasor sum of both components (Figure B.6).

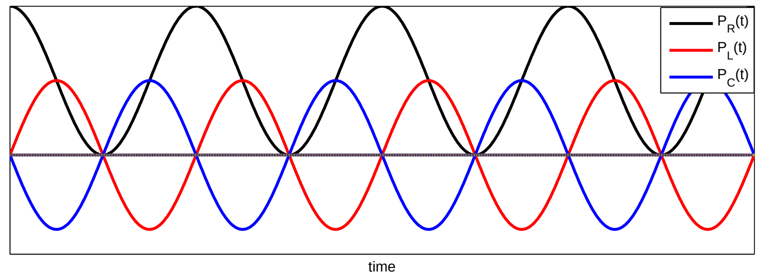

Figure B.5: Power waveforms in resistive, inductive and capacitive loads

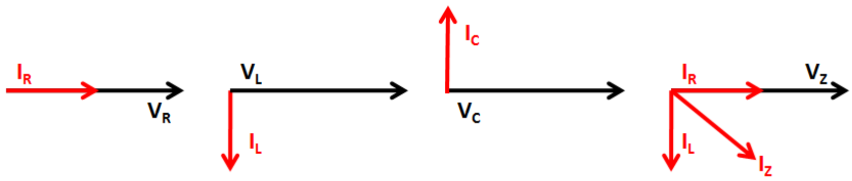

Figure B.6: Phasors in loads

B.2 Types of Electric Power

There are three groups of powers related to the different circuit loads: resistances, reactances, and impedances.

Table B.1: Active, reactive and aparent powers

Power	Unit	Definition
Active	W	$P = I^2R = \frac{V^2}{R}$
Reactive	VAr	$Q = I^2X = \frac{V^2}{X}$
Apparent	VA	$S = IV = I^2Z = \frac{V^2}{Z}$

- **Active Power**

  As it is the power capable of performing useful work, it is also called real power. It is measured in watts (W) and it can also be seen as the conversion of electrical energy into other forms such as mechanical work or heat.

  Active power is motivated by resistive loads where current and voltage components are in phase. The definition of this power is given by:

$$P = V_{rms}I_{rms}cos(\phi) \tag{B.8}$$

- **Reactive Power**

  Purely reactive loads such as coils and capacitors consume no electrical energy as they store it and dump it back into the source. However, as they drop voltage and draw current it seems that they do dissipate power. This power is called reactive power and it generates the magnetic fields which are essential for inductive electrical equipment to operate.

As reactive loads present current and voltage out of phase, reactive power will be ±90° in advance or in arrears the voltage waveform. This power is consumed due to presence of reactance in circuit such as motors, transformers or solenoids. Its unit is Volt-Amps reactive (VAr) and it is defined as:

$$Q = V_{rms} I_{rms} sin(\phi) \tag{B.9}$$

- **Apparent Power**

  Apparent power is the total power required by the load, the one that the power company supplies. It can be obtained through the vectorial sum of active and reactive power. Thus, it is measured in Volt-Amps (VA) and its definition is given by:

$$S = V_{rms} I_{rms} \tag{B.10}$$

B.3 Power Factor

IEEE and IEC define the Power Factor (PF) as the ratio between the active power and the apparent power. Like all ratio measurements, it is a dimensionless quantity which can be expressed as:

$$PF = \frac{P}{S} \tag{B.11}$$

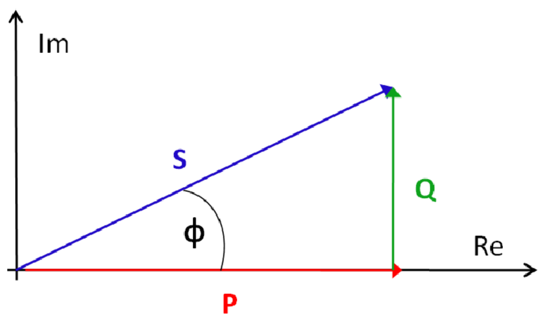

Figure B.7: Power triangle relating the three types of power [7] [8] [9] [10]

Figure B.7, represents the vectors of the three different powers: P, Q, and S. As real and apparent powers form the adjacent and hypotenuse sides of a right triangle, it is also possible to define the PF as the cosine of the angle between them.

$$PF = cos(\phi) \tag{B.12}$$

This new expresion confirms that the value of the power factor varies between 0 and 1 (although it can also be expressed as a percentage). The angle (ϕ) indicates the proportion of power transformed into useful work (P) from the total power (S) required by the load. However, this definition is only valid when both current and voltage are pure sinusoidal waves, and this occurs when the load is composed of linear elements [39].

In purely resistive loads, as there is no reactive power the cosine is maximum (PF = 1). However, for purely reactive loads such as inductors or condensators, the power factor is zero as now the active power is null.

In practice, loads are combinations of resistance, inductance, and capacitance and thus, PF lies between 0 and 1. Whenever the power factor is not maximun, the current does not follow the voltage wave. For that reason, the PF is also known as Displacement Power Factor [9].

If the current wave lags behind the voltage wave, it is said that its power factor is lagging and the circuit will be predominantly inductive. Conversely if the current leads the voltage, it is said that its power factor is leading and therefore, the circuit is predominantly capacitive.

Power factor is a measure of how efficiently or inefficiently electrical power is used. A load with a PF below 1 draws more current than a load with a high power factor for the same amount of useful power transferred. Higher currents increase the energy lost in the distribution system and require larger wires and other equipment. Therefore, a low PF describes an inefficient power delivery system.

The PF can be easily measured by using power factor meters. However, it is also possible to use an oscilloscope to compare the angle shift between the voltage and current waveforms and then calculate the cosine.

In the case of non-linear loads such as fluorescent lighting, the shape of the current waveform is not sinusoidal but undefined. The reason of this shape is the addition of harmonic currents (I_{rms}) to the original AC current ($I_{1,rms}$). As a result, a Distortion Power Factor (DPF) is defined to measure how much the harmonic distortion of a load's current decreases the average power transferred to the load. As the formulas below show, the Total Harmonic Distorsion (THD) must be zero for DPF to be unity.

$$DPF = \sqrt{\frac{1}{1+THD^2}} \tag{B.13}$$

$$PF = DPF\frac{I_{1,rms}}{I_{rms}} \tag{B.14}$$

B.3.1 Power Factor Correction

Electrical loads in AC circuits consume both real and reactive power. Consequently, their PF lies below the unity. As seen in the previous section, this situation increases the apparent power and the flowing current causing electric companies to install heavier wires that tolerate the excess current.

The electricity suppliers, will charge extra for the "unused" energy consumed (Q). Thus, high power factors are desired. Regulatory requirements establish the minimun housing PF around 0.95. For that reason, a Power Factor Correction (PFC) is usually needed.

Poor power factor can be corrected by supplying reactive power of opposite sign in order to cancel the inductive or capacitive effects of the load. Inductance will be canceled by capacitive reactance and vice versa. The aim of the PFC is to equal both apparent and real powers and thus, make the circuit look purely resistive.

Linear loads with low PF can be corrected with a passive network of capacitors or inductors. However, in non-linear loads where the current drawn from the system is distorted, active or passive power factor correction may be used to counteract this effect [38] [8].

- **Passive PFC**

  This is the simplest type of PFC. It uses a filter at the AC input to correct low power factor. The passive PFC circuitry uses only passive components: an inductor and some capacitors [8].

- **Active PFC**

  Active PFC involves complex circuitry to counteract the effects of the reactive power component. Although it is a more expensive method, active PFC is prefereable since it provides more efficient power frequency.

  This PFC is used when the inductor necessary for passive PFC of the circuit becomes too large for a feasible design. As an example, boost converters are used to accomplish this PFC.

To conclude, PFC improve the stability and efficiency of the circuits by reducing losses and improving voltage regulation at the load.

C
Introducción

C.1 Motivación

Vivimos en una época caracterizada por un envejecimiento sin precedentes. Un estudio sobre el envejecimiento establecido por la Agencia Estatal CSIC, determina que alrededor del 30% de la población española superará la edad de 65 años en 2050 [1]. Este fenómeno demográfico está afectando a todo el planeta y tendrá un impacto significativo en los sistemas de salud y pensiones en muchos países.

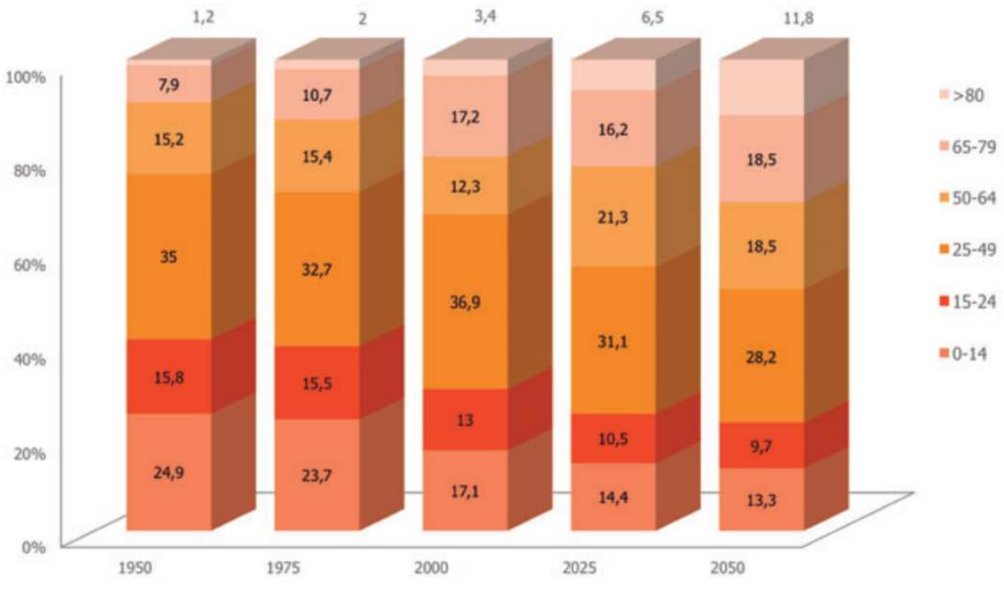

Figure C.1: Grupos estimados de población en la UE 25 entre 1950-2050 [1]

Esta situación tiene dos efectos importantes en la sociedad: el descenso del número de trabajadores y el aumento de la población que requiere muchos más cuidados. En otras palabras, la proporción de trabajadores con respecto a los jubilados está descendiendo en los últimos años. A consecuencia de esto, es necesario proporcionar los servicios adecuados para asegurar el bienestar de las personas mayores.

Diferentes estudios afirman que vivir de forma independiente es a menudo elección de las personas mayores. Por ejemplo, la AARP (Asociación Americana de Personas Retiradas) informó en julio del 2010 que el ochenta y ocho por ciento de los estadounidenses que superan los 65 años quieren quedarse el mayor tiempo posible en sus propias casas [11].

Table C.1: Personas a las que les gustaría permanecer en sus residencias actuales el mayor tiempo posible [11]

Opinión	**Edad**			**Género**	
	45-49 n=109	**50-64 n=542**	**65+ n=334**	**Masculino n=466**	**Femenino n=519**
Fuertemente o algo de acuerdo	81%	85%	88%	81%	89%
Fuertemente de acuerdo	60%	72%	78%	69%	76%
Algo de acuerdo	21%	13%	10%	12%	13%

Como resultado, el concepto de **Aging in Place** (cuya traducción en español sería envejecimiento en el lugar), intenta retrasar el traslado de las personas mayores permitiéndoles vivir de forma independiente el mayor tiempo posible de un modo seguro y cómodo. Esto implica asegurar el apoyo necesario para cubrir sus necesidades cambiantes mediante la adición de los servicios de atención en sus propias residencias [13].

Aunque los sistemas de salud de muchos países están normalmente dispuestos a gastar grandes cantidades de dinero para mantener institucionalizados a los ancianos de por vida, parecen poco dispuestos a gastarlo en servicios de asistencia doméstica (a pesar de ser una opción más económica y deseada).

En cambio, un estudio realizado en 2001 por la Universidad de Harvard [2] declara que la salud y la vivienda están interrelacionados: *"Cuando un medio de vida es asequible y apropiado, un individuo que envejece es más probable que se mantenga saludable e independiente"*.

Los sistemas de cuidados deben reflejar esta relación entre la salud y la vivienda, de manera que se eviten las ineficiencias en el cuidado de los ancianos debido a la existencia tanto de exceso de atención como la falta de ella. Estas ineficiencias pueden causar problemas e incrementar gastos. Por esa razón, los servicios y las instalaciones deben estar diseñados para satisfacer las necesidades del individuo en lugar de insertar a una persona en un servicio o facilidad ya existente[2].

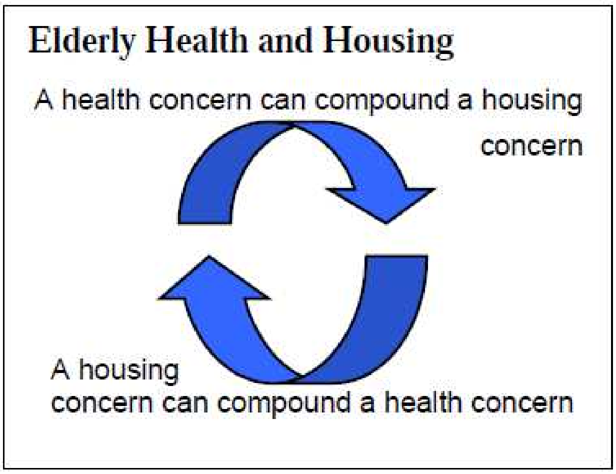

Figure C.2: Relación circular entre la salud de las personas mayores y la vivienda [2]

La motivación de este proyecto consiste por tanto desarrollar tecnologías que faciliten la independencia de aquellas personas que necesitan atención especial, como personas mayores o gente con discapacidades. Específicamente, se intenta incrementar la seguridad dentro de la cocina mediante la monitorización de los eventos del equipamiento eléctrico.

Con ese objetivo, se propone un sistema de monitorización capaz de mostrar qué electrodomésticos están siendo encendidos y apagados. Este método puede ayudar a personas con trastornos de memoria mediante la implementación de un sistema de alerta diseñado para la atención domiciliaria. Es decir, un sistema que avise al usuario cuando el dispositivo ha estado encendido por demasiado tiempo o qué electrodomésticos siguen encendidos al salir de casa.

Además, dado que los datos serán accesibles desde un navegador web, también es posible seguir las actividades diarias de una persona de forma remota. Por ejemplo, el sistema mostrará cuántas veces la persona ha cocinado o ha preparado el café en un día. Esta información puede ser útil para las enfermeras o familiares a cargo. Recibir más información pueden aliviar sus preocupaciones y, al mismo tiempo, prevenir o identificar problemas de salud (por ejemplo, el insomnio detectado por un comportamiento poco común) [14].

C.2 Objetivos

El principal objetivo de este proyecto es desarrollar un sistema de monitorización de actividades que sea capaz de identificar los eventos causados por electrodomésticos. Es decir, cuando dichos electrodomésticos son encendidos o apagados. Este sistema se llama en inglés Non-Intrusive Appliance Load Monitoring o también por sus siglas NIALM o NIALMS. El requerimiento especial que presenta NIALMS es que los eventos serán detecados en un único punto.

Para lograr este objetivo, es necesario medir las características de los diversos aparatos eléctricos con el fin de crear una base de datos. A partir de entonces, será posible diferenciarlos y determinar sus estados en todo momento. La idea es relacionar las actividades de cocina con los electrodomésticos. Dado que los dispositivos se pueden diferenciar por su comportamiento eléctrico, es posible determinar qué actividad se está llevando a cabo.

La extracción de las características eléctricas se realizó por medio de un medidor de potencia y procesado por los algoritmos de programación implementados. Se usó el lenguaje de programación Python así como el entorno de desarrollo web Django sobre una máquina Linux, con el fin de implementar el trabajo y permitir un desarrollo más fácil en el futuro. Una descripción de estas herramientas de software y hardware se detalla en el Capítulo 4.2.

Además, dado que este trabajo forma parte del proyecto DIEM - BA, diseñado para facilitar la interoperabilidad entre diferentes tipos de sistemas, este trabajo se integrará en una plataforma de alto nivel ya existente llamada ThereGate. Aunque la aplicación no se contempla en esta tesis (ya que consiste simplemente en añadir unas líneas más de código Python al programa), también se detalla una breve descripción de dicha plataforma en el Capítulo 4.2.

C.3 Descripción del progreso del trabajo

El desarrollo del prototipo implementado en este Proyecto Final de Carrera ha sido realizado en Aalto University (Finlandia). El desarrollo de este trabajo ha estado divido en las siguientes etapas:

1. **Proceso de Formación:**

Éste fue el punto de partida del proyecto donde los objetivos del mismo fueron definidos. Para lograr dichos objetivos, fue necesario adquirir conocimientos básicos mediante las lecturas de documentos relacionadas con NIALMS o Asistencia Automatizada.

El material empleado en este proyecto fue también elegido y adquirido en esta etapa. Mientras tanto, un proceso de aprendizaje en programación Python y el entorno Django se llevó a cabo mediante la documentación oficial encontrada en la web.

2. **Pruebas Básicas:**

   El propósito de esta etapa fue desarrollar la administración de la base de datos, el programa y la interfaz de usuario con el fin de demostrar que se pueden alcanzar los resultados esperados.

   Para hacerlo más sencillo, todas las actividades referentes a esta etapa fueron realizadas en el lugar de trabajo, reduciendo la instalación del medidor a una única entrada eléctrica. Por otra parte, solamente una cafetera y una lámpara fueron usadas como dispositivos de prueba.

3. **Pruebas de Laboratorio:**

   El propósito de este proyecto es obtener una implementación práctica de un sistema de monitorización que identifique actividades de cocina. Esta etapa fue mas complicada que la anterior dado que se aplica el trabajo desarrollado en las pruebas básicas a la cocina del departamento.

   Esta etapa fue por tanto la evolución de la anterior, lo cual implica mejoras en la administración de la base de datos, los algoritmos y la interfaz de usuario. La diferencia principal de ambas etapas reside en que esta presta más atención a los algoritmos de identificación mientras que la anterior se centra más en el desarrollo del sistema. Además, la implementación en la plataforma ThereGate fue realizada.

4. **Documentación, evaluación y escritura del informe:**

   Esta etapa se desarrolló a lo largo del proyecto aunque se hizo más relevante a medida que el proyecto avanzaba. Incluyó la recopilación de documentación, la evaluación del trabajo y la realización de la memoria.

   Además de esas actividades, una reunión y un informe fueron realizados cada semana a lo largo de la vida del proyecto con el fin de comentar progresos, enfoques y soluciones.

Las tareas anteriores se reflejan en el diagrama de Gantt (Figure C.3). El color rojo muestra cada una de las cuatro etapas previamente descritas mientras que el color azul muestra las actividades que comprenden esas tareas.

C.4 Estructura de la memoria

Este documento está estructurado de la siguiente manera:

- **Capítulo 1: Introducción**

  Este capítulo presenta la motivación, objetivos y estructura de este documento. Como este proyecto ha sido realizado en el extranjero, se incluye también una descripción del progreso de trabajo.

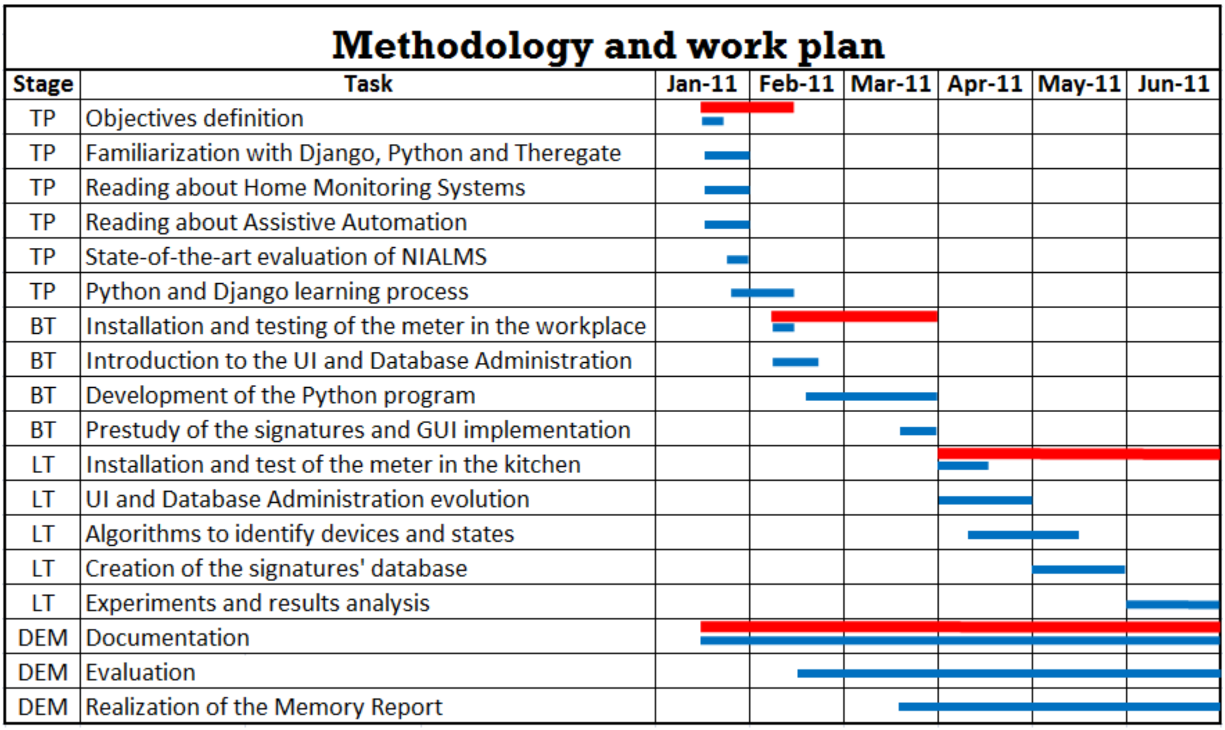

Figure C.3: Metodología y plan de trabajo presentado en un diagrama de Gantt

- **Capítulo 2: Monitorización de actividades humanas**

  In this chapter, the basic daily activities are described introducing concepts such as Assisted Living and Assisted Living Facilities. It also explains why the kitchen environment has been chosen for this monitoring system and which kind of electrical appliances can be found there.

  En este capítulo, se describen las principales actividades diarias introduciendo conceptos tales como Vida Asistida (Assisted Living en inglés) o Facilidades para la Vida Asistida (Assisted Living Facilities). También explica por qué la cocina ha sido elegida para ser monitorizada y qué tipo de electrodomésticos se pueden encontrar en ella.

  Además, se hace un resumen sobre la monitorización remota donde se destacan sus ventajas y razones por las que ha sido usado en este proyecto.

- **Capítulo 3: NIALMS**

  En este capítulo se hace una introducción a NIALMS incluyendo sus antecedentes, diferentes aplicaciones y características.

- **Capítulo 4: Diseño e implementación del sistema**

  El diseño e implementación de este trabajo son descritos en este capítulo incluyendo los algoritmos, el medidor de potencia, la administración de la base de datos y la interfaz de usuario.

  Además, este capítulo describe las herramientas hardware y software usadas para los sistemas de monitorización y grabación que comprenden este proyecto.

- **Capítulo 5: Tests y resultados**

  Este capítulo presenta los resultados experimentales para el test básico y el de laboratorio. Se representa una gráfica para la firma de cada dispositivo así se detalla un pequeño resumen de su funcionamiento.

- **Capítulo 6: Conclusiones y trabajo futuro**

  Este último capítulo resume los principales logros del trabajo, discute los resultados obtenidos y proporciona sugerencias para el trabajo futuro.

Un pequeño glosario ha sido incluido tras el último capítulo con el fin de hacer una breve explicación de los conceptos más importantes que aparecen en este documento.

D

Conclusiones y trabajo futuro

D.1 Resumen del trabajo realizado

En este Proyecto Final de Carrera, se ha implementadoo un prototipo de un sistema de monitorización no intrusivo de cargas de dispositivos (Non-Intrusive Appliance Load Monitoring System) con el propósito de monitorizar actividades humandas dentro de la cocina.

NIALMS se basa en un único medidor de potencia que mide constantemente el consumo total de potencia. Como muestra la Figura D.1, los eventos provenientes de los electrodomésticos hacen cambios tanto positivos como negativos en la demanda de carga eléctrica. Debido a que cada dispositivo consume diferente cantidad de potencia eléctrica, es posible reconocer el perfil de cada uno de ellos (firmas de dispositivos).

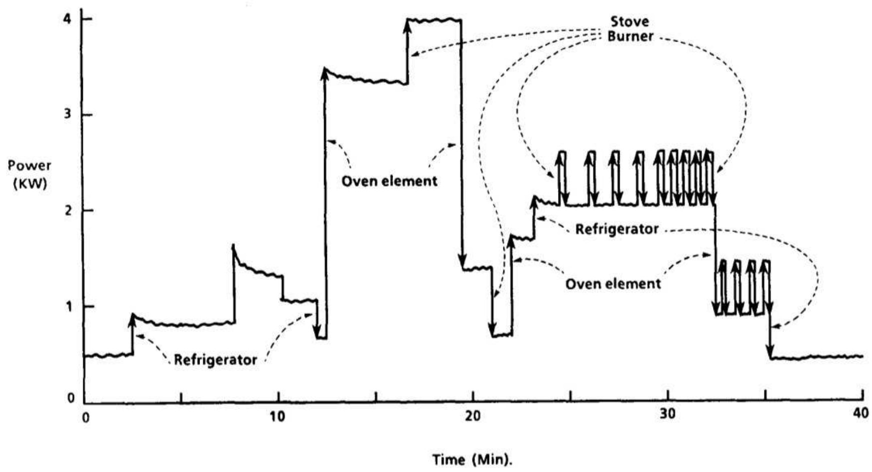

Figure D.1: Los eventos de electrodomésticos producen saltos en la carga total [5]

La implementación propuesta en este trabajo está dividida principalmente en dos: el sistema de grabación y el de monitorización. El sistema de grabación que consiste en el medidor de potencia, es responsable de realizar las medidas eléctricas y detectar los eventos. Por otro lado, el sistema de monitorización consiste a su vez en dos partes: algoritmos de identificación de carga, que relacionan cada evento con un dispositivo; y la interfaz pública, que es responsable de mostrar el historial de eventos al usuario mediante el protocolo HTTP.

El estado del arte de NIALMS propone diferentes métodos para la implementación de los algoritmos de identificación de carga. En este trabajo se ha elegido el análisis de conglomerados que consiste en una interpretación gráfica de dos dimensiones para las firmas de estado estacionario. La idea principal es hacer una base de datos con las firmas de los dispositivos. A partir de entonces, los algoritmos de identificación de carga serán capaces de reconocer el dispositivo que causó un evento al compararlo con la librería de firmas.

Después de que se desarrollara el sistema, se recogieron datos eléctricos de cada aparato con el fin de construir la base de datos. Además, el proceso de identificación se puso a prueba mediante la medición de varios aparatos combinados. Finalmente, el sistema fue implementado en una plataforma de alto nivel llamada ThereGate.

D.2 Conclusiones

NIALMS puede estimar el número y la naturaleza de cargas individuales, su consumo de energía y sus variables temporales de fecha y hora. Por esa razón, es posible usarlo con el fin de monitorizar actividades humanas. A pesar de que se ha demostrado que el comportamiento diario puede ser monitorizado con este procedimiento, los experimentos no fueron realizados dentro de un ambiente doméstico por lo que los resultados no son realistas en cuanto a actividades diarias se refiere.

Los resultados de este esudio revelan que es posible conseguir los objetivos propuestos mediante un simple análisis gráfico. Sin embargo, a mayor número de dispositivos mayor es la dificultad de identificación. De hecho, la exactitud de un sistema NIALM es muy dificil de evaluar. La precisión del sistema desarrollado depende en el número y el tipo de dispositivos que se usen así como la precisión con la que las firmas son definidas.

Como se ha visto en el Capítulo 5.2, los eventos del equipamiento eléctrico se distribuyen mayormente en el eje real entre los 50 y los 2400 W. Esto significa que la mayoría de los electrodomésticos de cocina son resistivos. Como consecuencia, existe el solapamiento de las firmas.

Por tanto, el sistema requiere un estudio más profundo de las firmas de los dispositivos. Los algoritmos desarrollados funcionan perfectamente, pero podría mejorarse el sistema si se añadiese un tercer parámetro a la definición de las firmas. En ese caso, la precisión del sistema incrementaría notablemente. Esto es lo que se hace en sistemas de monitorización avanzada a través de un análisis de Fourier de la corriente para la síntesis de los armónicos de la variación en el tiempo.

Como curiosidad de los resultados, decir que aunque las nuevas neveras (frigoríficos 1 y 3) parecen consumir más potencia que el antiguo (frigorífico 2), este último tiene un mayor número de ciclos en el mismo intervalo de tiempo.

D.2.1 Ventajas y desventajas de NIALMS

A diferencia de los sistemas de monitorización corrientes que utilizan varios sensores o medidores, NIALMS recopila la información eléctrica mediante el muestreo del consumo de potencia en un único punto. Esto supone menos comopnentes que instalar, mantener o quitar [5].

Además, la monitorización remota implementada en este trabajo da la posibilidad de consultar la información en cualquier momento y cualquier lugar a través de Internet. Ésto implica una gran ventaja debido a la reducción de costes y a la simplificación de la instalación. Lo que es más, la complejidad y los costes de NIALMS son independientes del número de dispositivos a monitorizar [5].

Los métodos intrusivos requieren un cierto grado de equipamiento para hacer la instalación y guardar los datos. Por tanto, no suponen una solución tan atractiva como los sistemas no intrusivos. Sin embargo, hay situaciones donde las técnicas no intrusivas no proporcionan suficiente información y por tanto, las técnicas intrusivas son necesarias. Esto significa que NIALMS también presenta algunas desventajas.

En primer lugar, NIALMS supone hardware simple pero software complejo debido al procesamiento y análisis de señales. Además, es necesaria una puesta en marcha manual para asignar nombres a las firmas de los dispositivos.

En segundo lugar, el sistema no es capaz de detectar todos los dispositivos. Como se ha visto en el test de laboratorio (Capítulo 5.2), el ruido proveniente del equipo de grabación hace imposible identificar dispositivos de bajo consumo. Además, los dispositivos que siempre están encendicos (e.j. teléfonos) son también invisibles para el grabador de eventos dado qe las firmas no aparecen nunca. Los electrodomésticos de consumo de potencia contínuamente variable (e.j. máquinas de coser) tampoco se pueden detectar. La razón es que tienen un número infinito de estados con con una gama verdaderamente continua de los niveles de potencia de operación, y por tanto no generan cambios constantes que puedan ser identificados por firmas. Actualmente, esto no supone ninguna limitación para monitorización residencial ya que no hay muchos dispositivos de este tipo. En cambio, es más importante en aplicaciones comerciales o industriales, donde estos dispositivos son más frecuentes [5]. Sistemas y algoritmos exclusivos deben ser diseñados y desarrollados para su detección.

Table D.1: Clasificación de varios electrodomésticos

Electrodomésticos	**Ejemplos**
Siempre on	cargas en stand-by, teléfonos, relojes, bombas de acuario, etc.
On-Off	monitores de ordenador, alumbrado eléctrico, cafeteras, tostadoras, etc.
MÃ¡quinas de estados finitos (FSM)	lavadoras, lavavajillas, impresoras, microondas, etc.
continuamente variables	minicadenas, iluminación regulada, máquinas de coser, taladros de velocidad variable, etc.

Otro problema son los errores que implica NIALMS debido a grandes agrupaciones de eventos. Las agrupaciones pequeñas resultan de dispositivos muy consistentes, especialmente calentadores resistivos. Éstas son muy fáciles de reconocer. Sin embargo, los dispositivos idénticos eléctricamente son imposibles de distinguir.

Además de los inconvenientes mencionados, NIALMS implica problemas relacionados con la privacidad de las personas ya que proporciona información privada. Por ejemplo, es posible saber si una persona está en casa o no, y más aún el lugar exacto en la casa de esa persona está y lo que él o ella está haciendo. Como solución, con el fin de proteger la privacidad de las personas, un sistema de seguridad debe ser implementado.

D.3 Trabajo futuro

Cada vez más profesionales del campo de la medicina están más inreresados en sistemas de monitorización en los hogares debido a que pueden ayudar a mantener y mejorar las condiciones de vida. Aunque este proyecto está centrado en la cocina, la monitorización de actividades podría ser utilizada en otros áreas tales como cuartos de baño o salones. Sin embargo, podría ser inapropiado para espacios más amplios debido a la creciente probabilidad de eventos simultaneos.

Con el fin de mejorar el sistema y combatir los inconvenientes mencionados en el apartado anterior, un desarrollo del sistema NIALM propuesto debería hacerse:

- La mayoría de los electrodomésticos de cocina son resistivos. Por tanto, la probabilidad de tener firmas que se superpongan es elevada. Esta situación podría evitarse insertando una reactancia conocida en las cargas. En otras palabras, es posible cambiar las firmas de los dispositivos incluyendo carga coapacitiva que mejore la identificación de los dispositivos. En cambio, este proceso requeriría modificar físicamente dichos dispositivos.
- Además, podrían controlarse los electrodomésticos remotamente a partir de la aplicación de monitoreo. Es decir, el usuario sería capaz de apagar dispositivos a través de la interfaz de usuario si se insertaran fusibles en los dispositivos. Sin embargo, esto supondría una instalación más elaborada del sistema.
- Por otro lado, a pesar de que la interfaz de usuario se ha hecho pensando en el acceso a personas mayores o con algún tipo de discapacidad, podrían haberse seguido los estándares de accesibilidad web para personas con discapacidad.
- Las mejoras del sistema implican además el medidor de eventos. Se debe investigar más en la disgregación de cargas con el fin de obtener una mejor identificación de eventos, especialmente con los dispositivos de baja potencia y eventos simultáneos.
- También, se debería desarrollar una puesta en marcha automática y un control de privacidad así como un algortimo que esconda los ciclos de los dispositivos de manera que, solo los eventos correspondientes con actividades humanas fueran mostrados al usuario.
- El desarrollo futuro del sistema también puede implicar el análisis de los ciclos de los equipos eléctricos, ya que es posible revelar fallos del dispositivo mediante el análisis de consumo de energía inusual o cambios en las características de los ciclos.

Las expectativas de NIALMS son muy altas para distintas aplicaciones (Capítulo 4.4.2) debido a su bajo costo y simple instalación. El seguimiento de la carga puede ser útil para usuarios, reguladores, servicios públicos, fabricantes de electrodomésticos y otros interesados[32]. Las expectativas más importantes en la actualidad comprenden aplicaciones relacionadas con la red de distribución de energía eléctrica, más conocida con el término inglés Smart Grid. Conocer cómo y cuándo se usa la electricidad permite adelantarse y facturar de un modo más inteligente.

Sin embargo, hay más aplicaciones donde NIALMS podría ser extremadamente importante pero que aún no han sido investigadas. Por ejemplo, en situaciones sin acceso físico a las cargas como en aplicaciones submarinas o extraterrestres [5].

E

Presupuesto

1) **Ejecución Material**
   - Compra de ordenador personal (Software incluido) 2.000 €
   - Compra del medidor de potencia 2.200 €
   - Alquiler de impresora láser durante 6 meses 250 €
   - Material de oficina 150 €
   - Total de ejecución material 4.600 €
2) **Gastos generales**
   - 16% sobre Ejecución Material 736 €
3) **Beneficio Industrial**
   - 6% sobre Ejecución Material 276 €
4) **Honorarios Proyecto**
   - 750 horas a 15 €/ hora 11.250 €
5) **Material fungible**
   - Gastos de impresión 200 €
   - Encuadernación 200 €
6) **Subtotal del presupuesto**
   - Subtotal Presupuesto 17.262 €
7) **I.V.A. aplicable**
   - 18% Subtotal Presupuesto 3.107,16 €
8) **Total presupuesto**
   - Total Presupuesto 20.369,16 €

Madrid, Octubre 2011

El Ingeniero Jefe de Proyecto

Fdo.: María Noemí Valero Pérez

Ingeniero Superior de Telecomunicación

F

Pliego de condiciones

Pliego de condiciones

Este documento contiene las condiciones legales que guiarán la realización, en este proyecto, de *A Non-Intrusive Appliance Load Monitoring System for Identifying Kitchen Activities*. En lo que sigue, se supondrá que el proyecto ha sido encargado por una empresa cliente a una empresa consultora con la finalidad de realizar dicho sistema. Dicha empresa ha debido desarrollar una línea de investigación con objeto de elaborar el proyecto. Esta línea de investigación, junto con el posterior desarrollo de los programas está amparada por las condiciones particulares del siguiente pliego.

Supuesto que la utilización industrial de los métodos recogidos en el presente proyecto ha sido decidida por parte de la empresa cliente o de otras, la obra a realizar se regulará por las siguientes:

Condiciones generales.

1. La modalidad de contratación será el concurso. La adjudicación se hará, por tanto, a la proposición más favorable sin atender exclusivamente al valor económico, dependiendo de las mayores garantías ofrecidas. La empresa que somete el proyecto a concurso se reserva el derecho a declararlo desierto.

2. El montaje y mecanización completa de los equipos que intervengan será realizado totalmente por la empresa licitadora.

3. En la oferta, se hará constar el precio total por el que se compromete a realizar la obra y el tanto por ciento de baja que supone este precio en relación con un importe límite si este se hubiera fijado.

4. La obra se realizará bajo la dirección técnica de un Ingeniero Superior de Telecomunicación, auxiliado por el número de Ingenieros Técnicos y Programadores que se estime preciso para el desarrollo de la misma.

5. Aparte del Ingeniero Director, el contratista tendrá derecho a contratar al resto del personal, pudiendo ceder esta prerrogativa a favor del Ingeniero Director, quien no estará obligado a aceptarla.

6. El contratista tiene derecho a sacar copias a su costa de los planos, pliego de condiciones y presupuestos. El Ingeniero autor del proyecto autorizará con su firma las copias solicitadas por el contratista después de confrontarlas.

7. Se abonará al contratista la obra que realmente ejecute con sujeción al proyecto que sirvió de base para la contratación, a las modificaciones autorizadas por la superioridad o a las órdenes que con arreglo a sus facultades le hayan comunicado por escrito al Ingeniero Director de obras siempre que dicha obra se haya ajustado a los preceptos de los pliegos de condiciones, con arreglo a los cuales, se harán las modificaciones y la valoración de las diversas unidades sin que el importe total pueda exceder de los presupuestos aprobados. Por consiguiente, el número de unidades que se consignan en el proyecto o en el presupuesto, no podrá servirle de fundamento para entablar reclamaciones de ninguna clase, salvo en los casos de rescisión.

8. Tanto en las certificaciones de obras como en la liquidación final, se abonarán los trabajos realizados por el contratista a los precios de ejecución material que figuran en el presupuesto para cada unidad de la obra.

9. Si excepcionalmente se hubiera ejecutado algún trabajo que no se ajustase a las condiciones de la contrata pero que sin embargo es admisible a juicio del Ingeniero Director de obras, se dará conocimiento a la Dirección, proponiendo a la vez la rebaja de precios que el Ingeniero estime justa y si la Dirección resolviera aceptar la obra, quedará el contratista obligado a conformarse con la rebaja acordada.

10. Cuando se juzgue necesario emplear materiales o ejecutar obras que no figuren en el presupuesto de la contrata, se evaluará su importe a los precios asignados a otras obras o materiales análogos si los hubiere y cuando no, se discutirán entre el Ingeniero Director y el contratista, sometiéndolos a la aprobación de la Dirección. Los nuevos precios convenidos por uno u otro procedimiento, se sujetarán siempre al establecido en el punto anterior.

11. Cuando el contratista, con autorización del Ingeniero Director de obras, emplee materiales de calidad más elevada o de mayores dimensiones de lo estipulado en el proyecto, o sustituya una clase de fabricación por otra que tenga asignado mayor precio o ejecute con mayores dimensiones cualquier otra parte de las obras, o en general, introduzca en ellas cualquier modificación que sea beneficiosa a juicio del Ingeniero Director de obras, no tendrá derecho sin embargo, sino a lo que le correspondería si hubiera realizado la obra con estricta sujeción a lo proyectado y contratado.

12. Las cantidades calculadas para obras accesorias, aunque figuren por partida alzada en el presupuesto final (general), no serán abonadas sino a los precios de la contrata, según las condiciones de la misma y los proyectos particulares que para ellas se formen, o en su defecto, por lo que resulte de su medición final.

13. El contratista queda obligado a abonar al Ingeniero autor del proyecto y director de obras así como a los Ingenieros Técnicos, el importe de sus respectivos honorarios facultativos por formación del proyecto, dirección técnica y administración en su caso, con arreglo a las tarifas y honorarios vigentes.

14. Concluida la ejecución de la obra, será reconocida por el Ingeniero Director que a tal efecto designe la empresa.

15. La garantía definitiva será del 4

16. La forma de pago será por certificaciones mensuales de la obra ejecutada, de acuerdo con los precios del presupuesto, deducida la baja si la hubiera.

17. La fecha de comienzo de las obras será a partir de los 15 días naturales del replanteo oficial de las mismas y la definitiva, al año de haber ejecutado la provisional, procediéndose si no existe reclamación alguna, a la reclamación de la fianza.

18. Si el contratista al efectuar el replanteo, observase algún error en el proyecto, deberá comunicarlo en el plazo de quince días al Ingeniero Director de obras, pues transcurrido ese plazo será responsable de la exactitud del proyecto.

19. El contratista está obligado a designar una persona responsable que se entenderá con el Ingeniero Director de obras, o con el delegado que éste designe, para todo relacionado con ella. Al ser el Ingeniero Director de obras el que interpreta el proyecto, el contratista deberá consultarle cualquier duda que surja en su realización.

20. Durante la realización de la obra, se girarán visitas de inspección por personal facultativo de la empresa cliente, para hacer las comprobaciones que se crean oportunas. Es obligación del contratista, la conservación de la obra ya ejecutada hasta la recepción de la misma, por lo que el deterioro parcial o total de ella, aunque sea por agentes atmosféricos u otras causas, deberá ser reparado o reconstruido por su cuenta.

21. El contratista, deberá realizar la obra en el plazo mencionado a partir de la fecha del contrato, incurriendo en multa, por retraso de la ejecución siempre que éste no sea debido a causas de fuerza mayor. A la terminación de la obra, se hará una recepción provisional previo reconocimiento y examen por la dirección técnica, el depositario de efectos, el interventor y el jefe de servicio o un representante, estampando su conformidad el contratista.

22. Hecha la recepción provisional, se certificará al contratista el resto de la obra, reservándose la administración el importe de los gastos de conservación de la misma hasta su recepción definitiva y la fianza durante el tiempo señalado como plazo de garantía. La recepción definitiva se hará en las mismas condiciones que la provisional, extendiéndose el acta correspondiente. El Director Técnico propondrá a la Junta Económica la devolución de la fianza al contratista de acuerdo con las condiciones económicas legales establecidas.

23. Las tarifas para la determinación de honorarios, reguladas por orden de la Presidencia del Gobierno el 19 de Octubre de 1961, se aplicarán sobre el denominado en la actualidad "Presupuesto de Ejecución de Contrata" y anteriormente llamado "Presupuesto de Ejecución Material" que hoy designa otro concepto.

Condiciones particulares.

La empresa consultora, que ha desarrollado el presente proyecto, lo entregará a la empresa cliente bajo las condiciones generales ya formuladas, debiendo añadirse las siguientes condiciones particulares:

1. La propiedad intelectual de los procesos descritos y analizados en el presente trabajo, pertenece por entero a la empresa consultora representada por el Ingeniero Director del Proyecto.

2. La empresa consultora se reserva el derecho a la utilización total o parcial de los resultados de la investigación realizada para desarrollar el siguiente proyecto, bien para su publicación o bien para su uso en trabajos o proyectos posteriores, para la misma empresa cliente o para otra.

3. Cualquier tipo de reproducción aparte de las reseñadas en las condiciones generales, bien sea para uso particular de la empresa cliente, o para cualquier otra aplicación, contará con autorización expresa y por escrito del Ingeniero Director del Proyecto, que actuará en representación de la empresa consultora.

4. En la autorización se ha de hacer constar la aplicación a que se destinan sus reproducciones así como su cantidad.

5. En todas las reproducciones se indicará su procedencia, explicitando el nombre del proyecto, nombre del Ingeniero Director y de la empresa consultora.

6. Si el proyecto pasa la etapa de desarrollo, cualquier modificación que se realice sobre él, deberá ser notificada al Ingeniero Director del Proyecto y a criterio de éste, la empresa consultora decidirá aceptar o no la modificación propuesta.

7. Si la modificación se acepta, la empresa consultora se hará responsable al mismo nivel que el proyecto inicial del que resulta el añadirla.

8. Si la modificación no es aceptada, por el contrario, la empresa consultora declinará toda responsabilidad que se derive de la aplicación o influencia de la misma.

9. Si la empresa cliente decide desarrollar industrialmente uno o varios productos en los que resulte parcial o totalmente aplicable el estudio de este proyecto, deberá comunicarlo a la empresa consultora.

10. La empresa consultora no se responsabiliza de los efectos laterales que se puedan producir en el momento en que se utilice la herramienta objeto del presente proyecto para la realización de otras aplicaciones.

11. La empresa consultora tendrá prioridad respecto a otras en la elaboración de los proyectos auxiliares que fuese necesario desarrollar para dicha aplicación industrial, siempre que no haga explícita renuncia a este hecho. En este caso, deberá autorizar expresamente los proyectos presentados por otros.

12. El Ingeniero Director del presente proyecto, será el responsable de la dirección de la aplicación industrial siempre que la empresa consultora lo estime oportuno. En caso contrario, la persona designada deberá contar con la autorización del mismo, quien delegará en él las responsabilidades que ostente.